NASA TECH BRIEFS

Winter 1994
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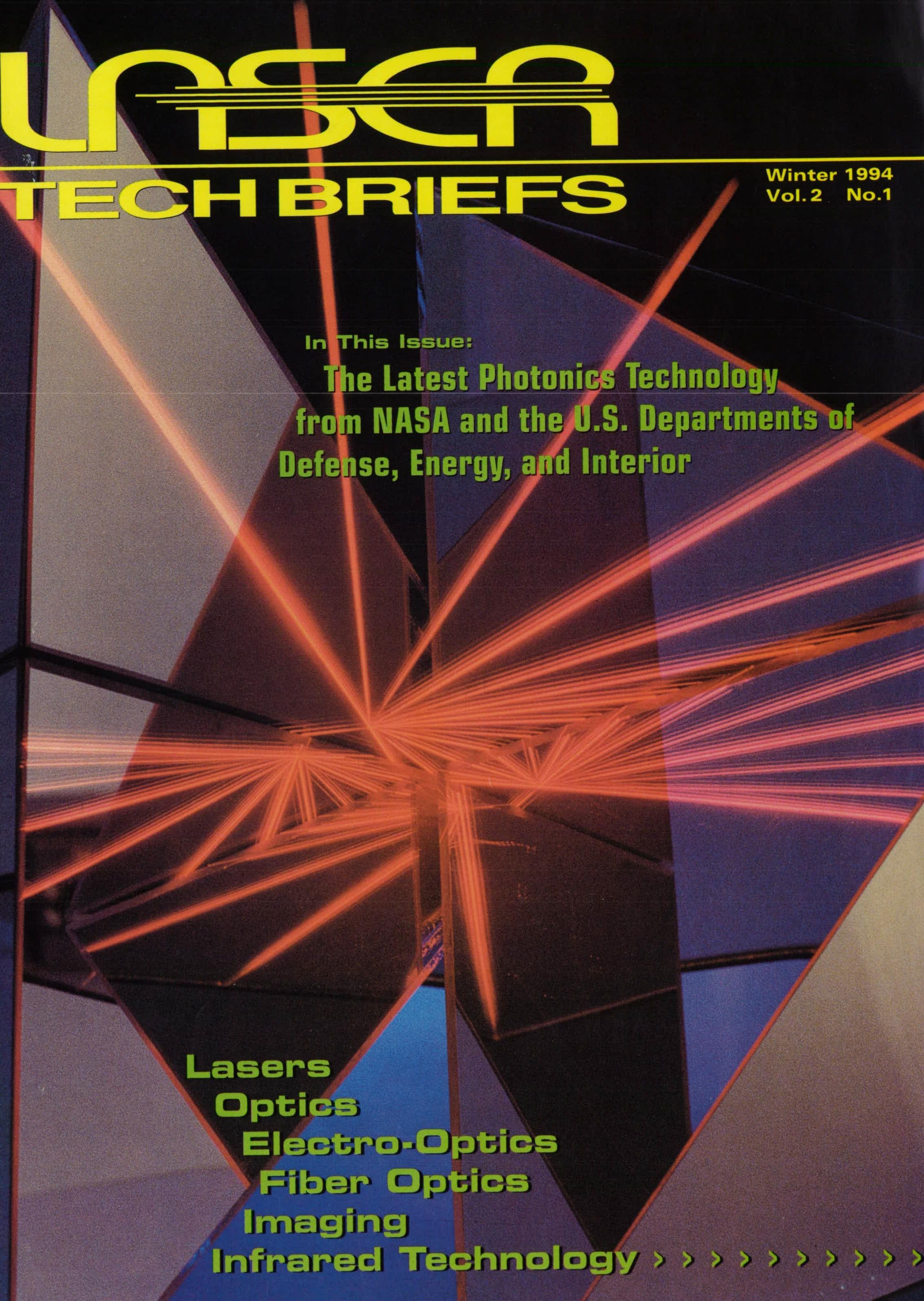


In This Issue:

The Latest Photonics Technology from NASA and the U.S. Departments of Defense, Energy, and Interior

Lasers

Optics

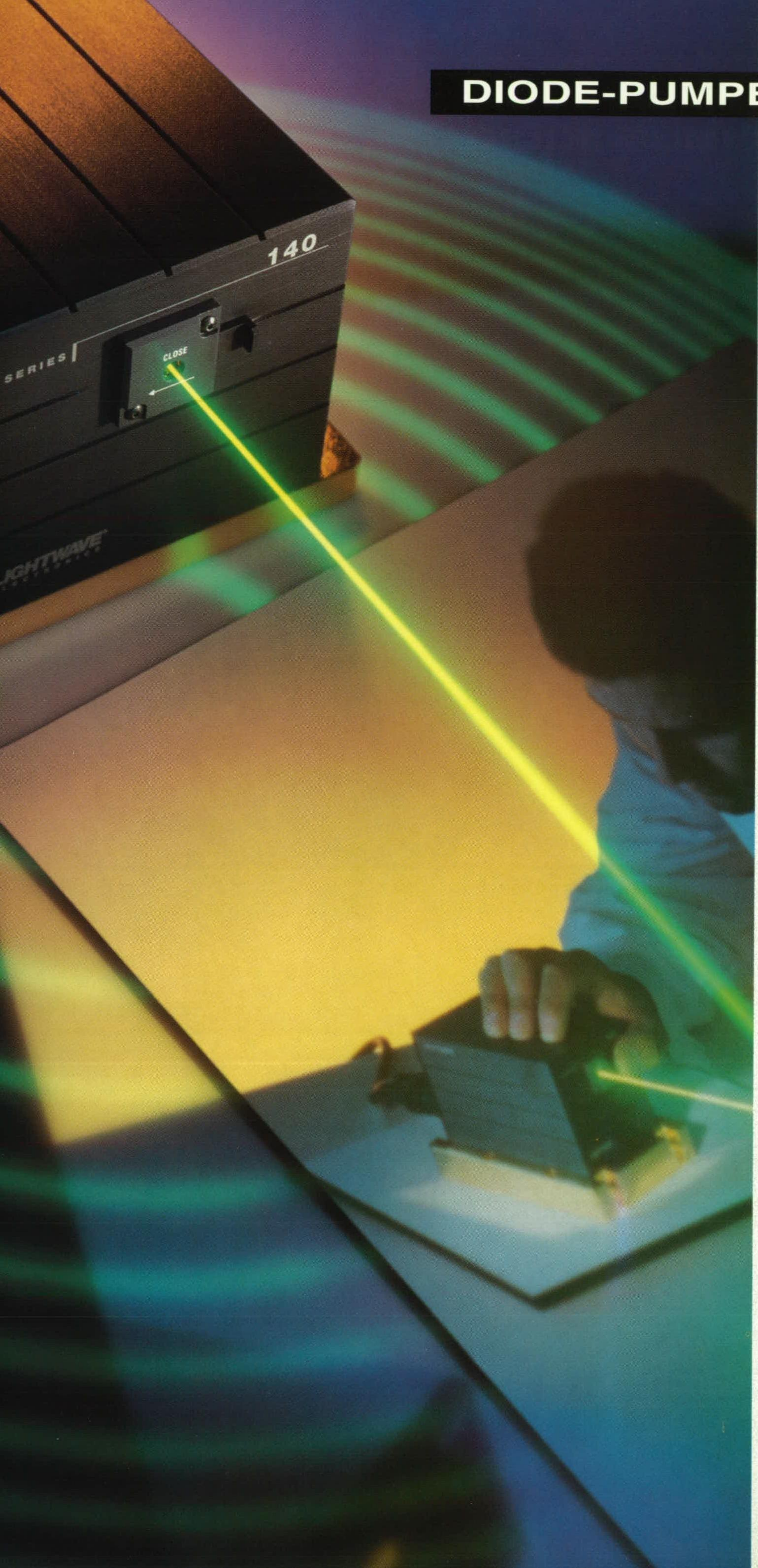
Electro-Optics

Fiber Optics

Imaging

Infrared Technology ›››››››››››

DIODE-PUMPED LASERS



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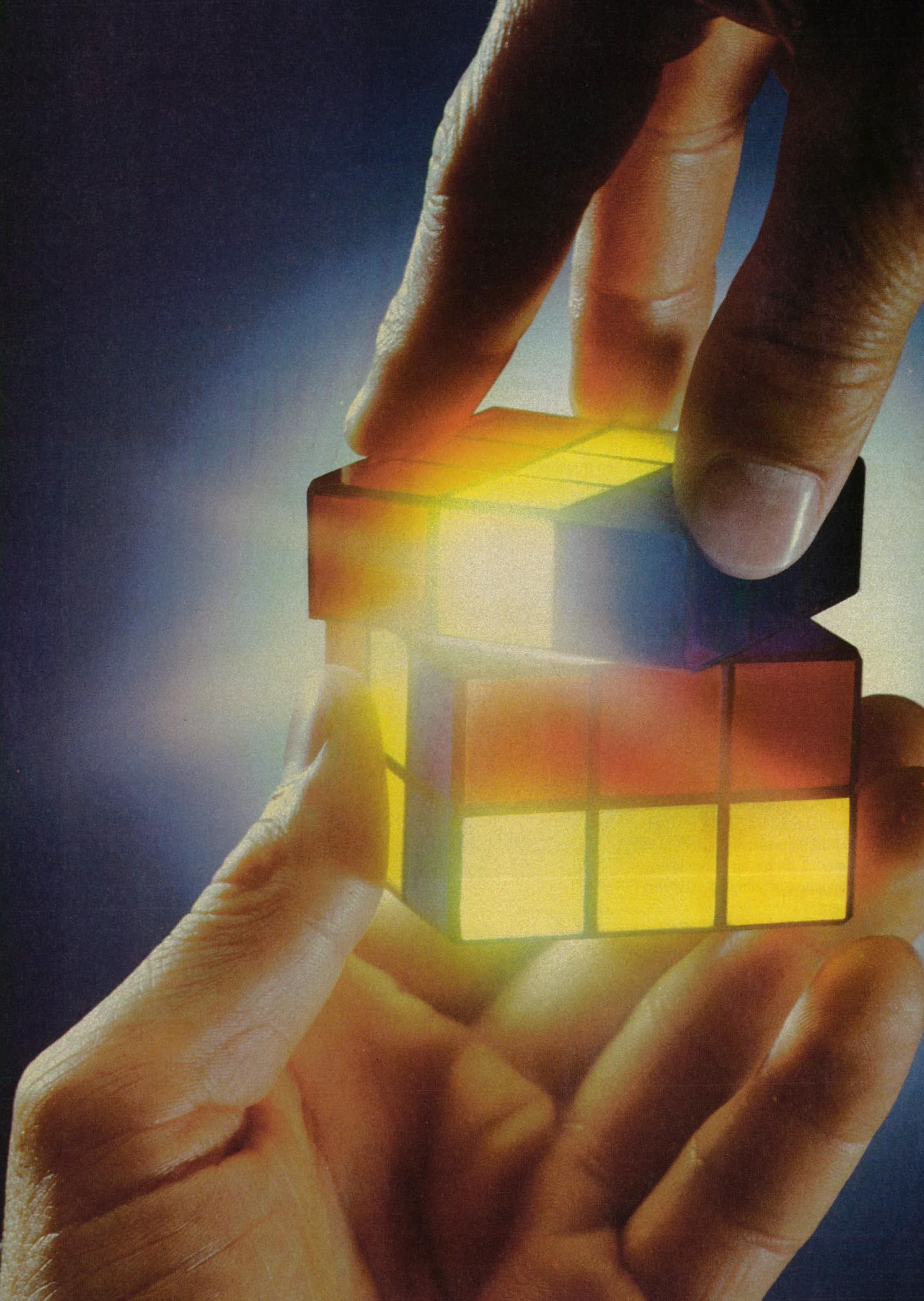

LASER TECH BRIEFS

WINTER 1994
Vol. 2 No. 1

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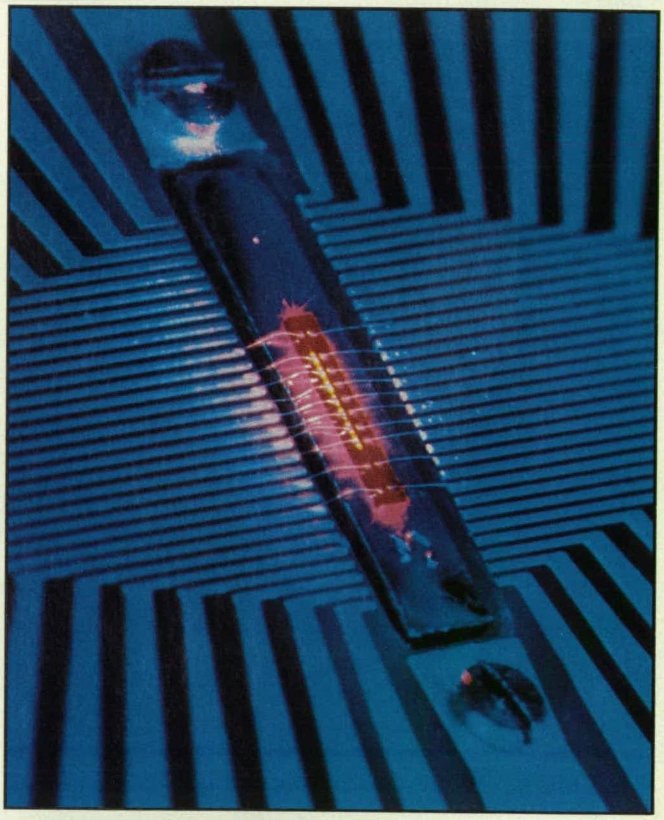
TECHNICAL SECTION



Shown is a 1-cm-long 30mW continuous-wave surface-emitting master oscillator power amplifier developed at the David Sarnoff Research Center, Princeton, NJ. Active outcoupling extracts coherent light within 0.05cm from where it is generated by amplifying the injected master oscillator signal. By allowing such long devices to operate with high efficiency, the technique makes possible an order of magnitude greater coherent power than is obtained from a conventional index-guided edge-emitting diode laser. See the tech brief on page 26.

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DEPARTMENTS

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EDITORIAL NOTEBOOK

Robert S. Clark
Editor

This issue of *Laser Tech Briefs*, the first for which I have acted as editor, is also the first to encompass briefs from federal laboratories not associated with NASA. And the firsts don't stop there: this is the first time any magazine has taken its readers behind the scenes into a broad range of labs developing photonics technology under the US government's aegis. The authors of these tech briefs are the engineers and researchers actually doing the work, and they present it with a view to how it might be useful to designers and engineers or commercially exploitable by industry. That makes *Laser Tech Briefs* unique among magazines that deal with photonics technology.

Six NASA labs are represented in these pages: Lewis Research Center, Marshall Space Flight Center, Jet Propulsion Laboratory, Johnson Space Center, Langley Research Center, and Goddard Space Flight Center. They are joined by nine non-NASA labs from the Departments of Defense, Energy, and Interior: Air Force Rome Laboratory, Brookhaven National Laboratory, Lawrence Livermore National Laboratory, David Sarnoff Research Laboratory, Army Ft. Monmouth Laboratory, the Bureau of Mines' Pittsburgh Research Center, the University of New Mexico's Center for High Technology Materials, Sandia National Laboratories, and Air Force Phillips Laboratory.

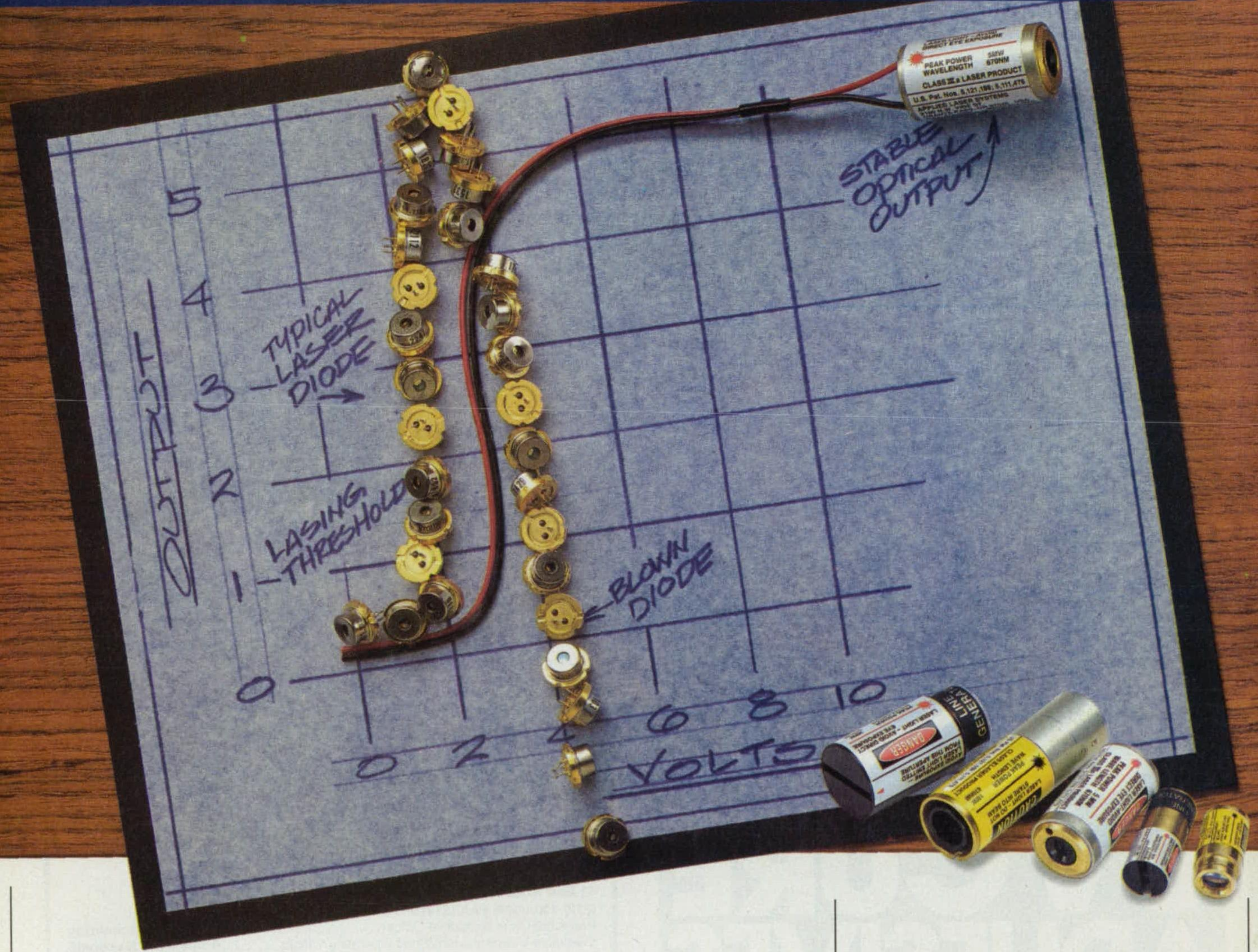
All have active and productive programs in widely diverse areas of photonics technology. But this is just the beginning. We are currently working with numerous other federal laboratories that are eager to contribute to future issues of *Laser Tech Briefs*. Their presence will cement our standing as the premier vehicle for bringing the wealth of innovation in the federal laboratories to the attention of designers and engineers in industry.

Looking beyond the briefs, each issue will profile the technology transfer program of a laboratory engaged in photonics research. This month *Laser Tech Briefs* features not a lab as such, but rather the Alliance for Photonic Technology, a cooperative association linking the technology transfer activities of four New Mexico laboratories. See the story "Alliance for Photonic Technology: Putting Industry Needs First," elsewhere in this issue.

In future issues the magazine will break more new ground: *Laser Tech Briefs* will take readers inside industrial and university laboratories conducting important photonics research with federal support, with special attention to those seeking industrial partners. Another editorial series will trace the paths taken by manufacturers in successfully converting innovative technology into a laser, optical, or optoelectronic product.

Laser Tech Briefs' editorial vision goes from alpha to omega, from raw idea to finished article. We invite you to accompany us each step of the way.

What Goes Up, Usually Comes Down...



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...the laser diode destined for your product application is completely protected against the forces of electro-static discharge, temperature and handling abuse. That's because a raw laser diode is a fragile and highly volatile device with extreme threshold behavior that will quickly "blow up" under unstable environmental conditions. The typical laser diode is capable of turning on in "one millionth" of a second...and one very short "mistake" usually results in total destruction, rendering the laser diode useless. Applied Laser Systems (ALS) has solved this problem and makes the laser diode usable in the real world.

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How You Can Access Technology Transfer Services at Federal Laboratories Featured in This Issue

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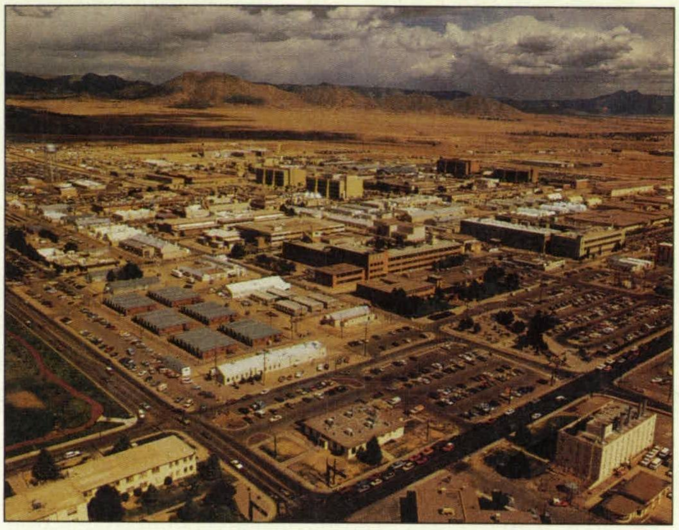


The Department of Energy's Sandia National Laboratories installation near Albuquerque, New Mexico, is one of the four research and development partners in the Alliance for Photonic Technology.

ALLIANCE FOR PHOTONIC TECHNOLOGY

Putting Industry Needs First

The Alliance for Photonic Technology sprang to life in the fertile valley of the Rio Grande River in New Mexico in July of 1991, with the formal signing of a memorandum of agreement between the four partners: Los Alamos National Laboratory, Sandia National Laboratories, US Air Force Phillips Laboratory, and the Center for High Technology Materials (CHTM) of the University of New Mexico. The conditions that make it an exemplar of technology transfer are unique: four laboratories with significant R&D programs in photonics, linked by physical proximity—each is within a few hours' drive of Albuquerque—and nurtured in its aims by the state's Economic Development Department. Yet its work can serve as a roadmap for technology reinvestment planners everywhere.

It was an initiative by New Mexico's two senators, Pete Domenici and Jeff Bingaman, that led to the Alliance's creation. While crafting the National Competitiveness Technology Transfer Act of 1989, the two wanted to insure that the state's Department of Energy laboratories had the same Cooperative Research and Development Agreement (CRADA) authority that civil service laboratories had been exercising since 1986. But the Alliance's mission quickly expanded beyond this initial impulse: in the terse formulation of William P. Latham of Phillips Lab, an early Alliance interim director, "International competitiveness of US industry is the primary goal of APT."

Today APT's formal mission statement embraces not only US competitiveness in photonics, but the following additional aims: to accelerate technology transfer to US industry, to contribute to New Mexico's economic development, to improve communications and technical interactions among its R&D participants, and to develop a core of support for its participants outside their traditional sources.

APT's structure is designed to facilitate these goals. Currently each of the R&D participants assigns a representative to an advisory board that oversees the activity of APT's director and staff. The director is assisted by four associate directors, each again representing one constituent, and by a research and development committee and four current working groups. An industrial advisory board is in the process of being formed.

In its fledgling stage, led by its first interim director, Larry Anderson, APT reached out to US industry by organizing technical meeting exhibits, visiting prospective industrial partners, hosting APT visits for companies, including laboratory visits, and answering phone inquiries. That its efforts paid off is apparent from the fact that, in 1992 alone, its initiatives yielded 13 CRADAs valued at $53 million, and a list issued that year offered more than 100 patents available for licensing from the R&D participants.

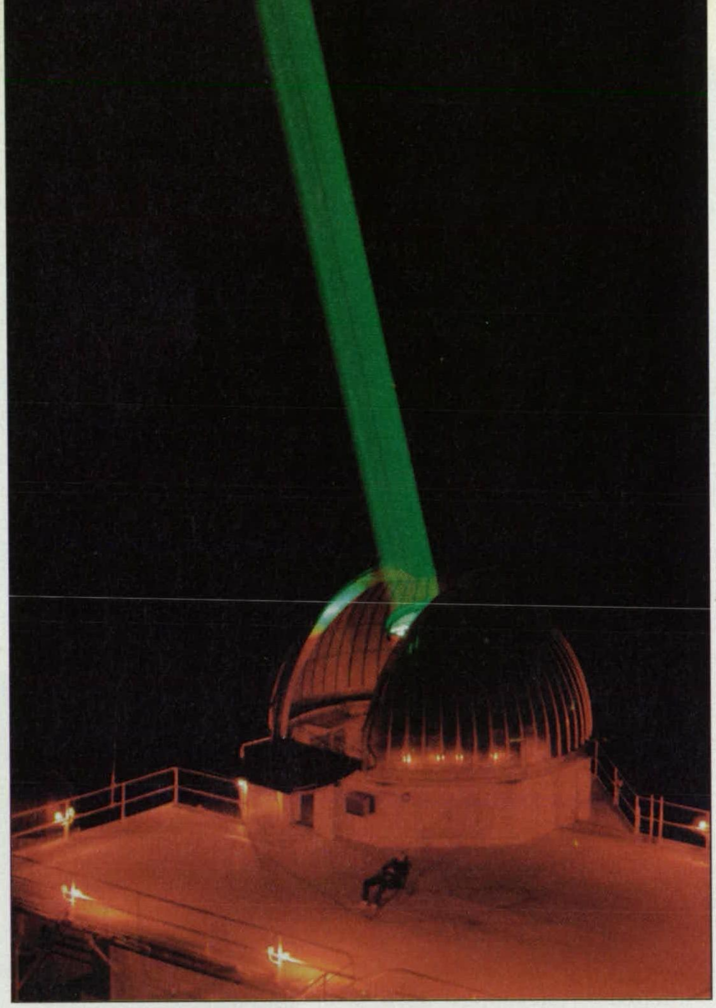
APT activities are sure to get a lift from the appointment early last year of the organization's first permanent director. Dr. Concetto Giuliano, widely known in the photonics industry by his nickname "Connie," brings to the position a distinguished professional lifetime of experience in photonics, for many years with Hughes Aircraft Research Laboratories and most recently with Textron in Maui, Hawaii.

Giuliano summarizes the work of APT in three steps: identify the needs in the private sector, identify the capabilities among the R&D partners, and match them. To deliver this message during the year just past, APT participated in six exhibits, and in addition attended seven technical conferences and five technology transfer/policy conferences. Giuliano also made a number of personal and professional contacts and industrial laboratory site visits, resulting, he says, in the growth of

APT's customer contact database by 70% to 1250.

An APT Technical Interchange Conference in Photonics planned for the coming spring aims to enhance communication among the R&D partners, according to Giuliano. Though the technical presentations will be limited to APT's R&D partners, Giuliano intends to invite industrial representatives interested in finding a fit of APT capabilities to their requirements.

As an example of the role of the working groups, which have embraced such areas as flat-panel displays and medical applications of lasers, the year-old Optical Sensors and Photonic Devices Working Group (OSWG) numbers 17 members from the four labs. With about 75 responses from a questionnaire concerning photonic sensors and devices available for technology transfer by APT participants, OSWG put together an Optical Sensors and Photonic Devices Database. It exists on Filemaker Pro for Macintosh and can be exported to many other formats as well. A related APT Optical Sensors and Photonic Devices Directory was scheduled for printing last month.



At the US Air Force Phillips Laboratory's Starfire Optical Range, a copper vapor imaging laser beams upward from the 1.5-meter-aperture telescope, which, in conjunction with a newly operational 3.5-meter-aperture unit, probes the atmosphere and uses a deformable mirror to correct aberrations in real time.

SEARCHING FOR SYNERGIES

The APT approach to technology transfer, according to the director, differs in significant ways from the commonplace. It emphasizes competitive-phase joint development with industry, focusing on customer goals. Wherever possible development projects are driven by market, product, and application needs. And finally, APT gives special attention to the synergies between its several constituent members.

Though each of APT's participants has capabilities stretching across the photonic technologies, one of the advantages offered by APT is its awareness of the synergy of such capabilities when they are pooled. The Center for High Technology Materials has particular strength in materials growth, Sandia in device processing and modeling, Phillips in diagnostics, and Los Alamos in innovative applications. But when considered in combination, the available facilities, the variety of program funding, and the research interests of the staff constitute a whole that is greater than the sum of its parts.

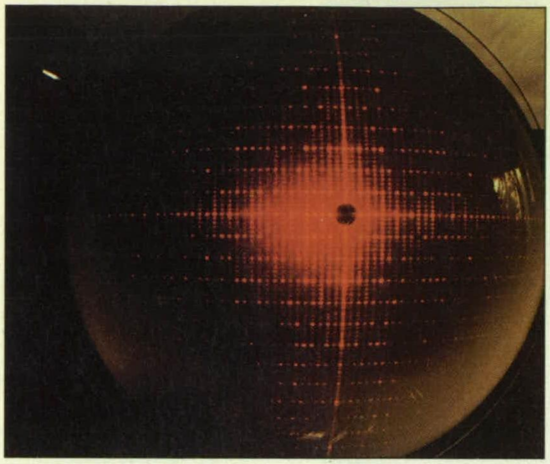
Of course, none of the laboratories is limited to photonics work alone, and the CHTM is part of the University of New Mexico's Optical Sciences Program, which offers a Ph.D. jointly administered by the Physics and Astronomy and the Electrical Engineering and Computer Engineering departments. Yet even when confined to photonics, the individual capabilities are considerable.

Los Alamos National Laboratory has major programs in lasers, fiber optic communications links and sensors, nonlinear optical components, electro-optics and infrared detectors. Along with extensive materials characterization capabilities and a high-speed (100 GHz) device characterization laboratory, it has 2500 square feet devoted to electronic device fabrication.

Los Alamos' work in optical sensing, though once dictated by the severe environmental demands of specific weapons development, has proven to have applications in the commercial sector, particularly in environmental sensing and medical applications. Within the Chemistry and Laser Sciences division, programs in coherent Raman spectroscopy, laser-induced fluorescence and laser-induced breakdown spectroscopy, as well as lidar, are useful in combustion chemistry and in contaminant monitoring of soils and the atmosphere. In the same division the focus of medical diagnostics effort is on laser ablation using 1-10W 800nm diode lasers coupled into optical fibers for urology and other surgical applications.

In the sector of fiber optic sensors, a wide variety of work, once driven by nuclear testing and related security issues, now goes on in measurement of electrical current, magnetic fields using Faraday rotation, optical time domain reflectometry and resonant-ring techniques, optical-emission temperature measurement, and neutron imaging using scintillating fibers. One device already being characterized in the field is an interferometric fiber optic load sensor that records signatures from ground compression caused by passing vehicles. An array of such sensors could measure traffic flow and vehicle weight, velocity, and position from beside, rather than beneath, the road.

Sandia National Laboratories are conducting major programs in surface- and edge-emitting laser diodes and



A dome scatterometer at the University of New Mexico's Center for High Technology Materials shows diffraction patterns from illuminating a 256K static random access memory fabricated at Sematech. The patterns reveal properties of the structure, such as line width and height.

arrays, visible and infrared modulators, image acquisition and analysis, waveguides and detectors, optical signal processing systems, optical logic elements, and wide-bandgap materials.

Devices resulting from work at Sandia include a reflectance-based fiber chemical sensor, a new class of chemical detector based on the change in reflectivity of thin metal and/or polymeric films deposited on the end of an optical fiber. Its uses include detection of trichlorothyrene, hydrogen gas, and many other chemicals. Another development is a glucose monitor that uses infrared light to measure blood sugar, employing infrared spectroscopy and advanced statistical techniques that were originally developed to analyze aging explosives.

Sandia also is participating in a joint effort to develop technology for a monitoring system to detect and characterize high-energy lasers firing into the atmosphere. Sandia's Optoelectronic Design Department has developed an optical sensor capable of measuring average incident irradiance, signal wavelength, and a two-dimensional angle of departure from 300 meters while "looking" into a brightly sunlit sky.

EXAMINING LASER BEHAVIOR

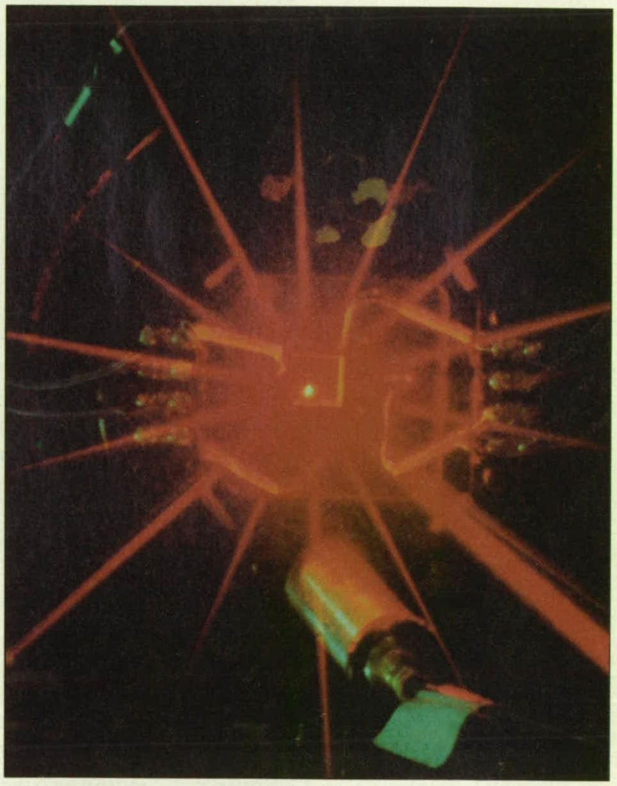
At the US Air Force's Phillips Laboratory there are more than 9000 square feet devoted to research labs with state-of-the-art diagnostic equipment and computer modeling support from workstations to a Cray 2. Phillips' programs range from nonlinear coupling of lasers and nonlinear optics to examinations of the behavior of mid-infrared lasers and spatial light modulators. Phillips also manages all of the Air Force's telescope installations, including the Starfire Optical Range, located with it at Kirtland Air Force Base.

The Starfire Optical Range performs field experiments on, and analyses of the problems imposed by, atmospheric turbulence on propagating optical radiation. One significant area of experimentation is the use of adaptive optics to perform real-time compensation for atmosphere-induced aberrations. Equipment includes a 1.5-meter-aperture telescope, a 1-meter-aperture coelostat beam director, smaller telescopes used for atmospheric measurements, and an extensive adaptive optics laboratory with a second-generation adaptive optics system and four deformable mirrors.

A strikingly different component from the Phillips Laboratory is now commercially available. Part of a Laser Medical Pac still under development, the laser component is tunable from the visible red to the mid-infrared and can provide different tissue interactions. The Pac is powered by two 2V batteries to operate the laser and one 9V battery for the electronics. The laser light is delivered to the instrument by fiber optic cable, providing very intense power density at the tip. The Medical Pac currently is being evaluated as a means of stopping bleeding.

The University of New Mexico's Center for High Technology Materials concentrates on optoelectronic and semiconductor development. Among its facilities are class-100 clean rooms, metallorganic chemical vapor deposition (MOCVD) and liquid-phase epitaxy chambers for submicron device fabrication, and analytical capabilities ranging from scanning electron microscopy and tunnelling electron microscopy to various field-emission spectroscopies. The optics program revolves around femtosecond linear and nonlinear spectroscopies, and thin film research.

The Alliance for Photonic Technology characterizes itself as a facilitator, not a contracting agent: all contracts on joint undertakings or licensing are done directly between the customer company and the Alliance's R&D participants. Its part is to add value. With its in-depth knowledge of the capabilities of and synergies among its participants, specific contacts within the labs, and on-site project coordination, the Alliance offers a single point through which to obtain access to the labs' multiple facilities. ❑



The highest-power continuous-wave red laser beam ever produced was demonstrated recently at the Phillips Laboratory's Chemical Laser Facility. Nearly 700 watts was produced at 657 nanometers by using a lithium iodate nonlinear crystal in a focused beam external to the laser cavity to frequency-double the 1.315-micrometer output of the RotoCOIL high-power chemical oxygen-iodine laser.

Electronic Components and Circuits

Vertical-Cavity Microlasers Move Into the Visible

Breakthroughs in operating efficiency and visible wavelength emission promise wide applications for semiconductor microlasers.

Sandia National Laboratories, Albuquerque, New Mexico

A variety of applications will soon see a series of new vertical-cavity microlasers. By combining pioneering strained-layer semiconductors with precise methods for the growth of epitaxial heterojunction mirrors, the barrier to obtaining visible-light emission as well as the barrier of high electrical resistance which previously limited the operating efficiency, and thus the practical utility, of these laser devices have been overcome. It is now conceivable that more than 100,000 of these microlasers could be grown on a single 2-inch wafer, with each tiny laser putting out enough power to pump light through an optical fiber.

Vertical-cavity microlasers rely on stacks of heterojunction mirrors formed along the surface plane that create a Fabry-Perot cavity around an active gain region. These vertical-cavity surface-emitting lasers, or VCSELs (pronounced "vixels"), emit light directly out of the surface of the semiconductor from which they are grown. Compared to the traditional edge-emitting semiconductor lasers, VCSELs, with their emission perpendicular to the chips' surface, make it easier to fashion closely-packed arrays of lasers, produce tight, circular beams, and couple more easily to optical fibers. Perhaps equally significant is the fact that, whereas edge-emitting diode lasers must be individually cleaved, aligned, and packaged before use, VCSELs can be fully fabricated and tested directly on the semiconductor wafer using integrated circuit technology. Hence these devices could play the same role in the miniaturization of lasers as integrated circuits played for the miniaturization of transistors.

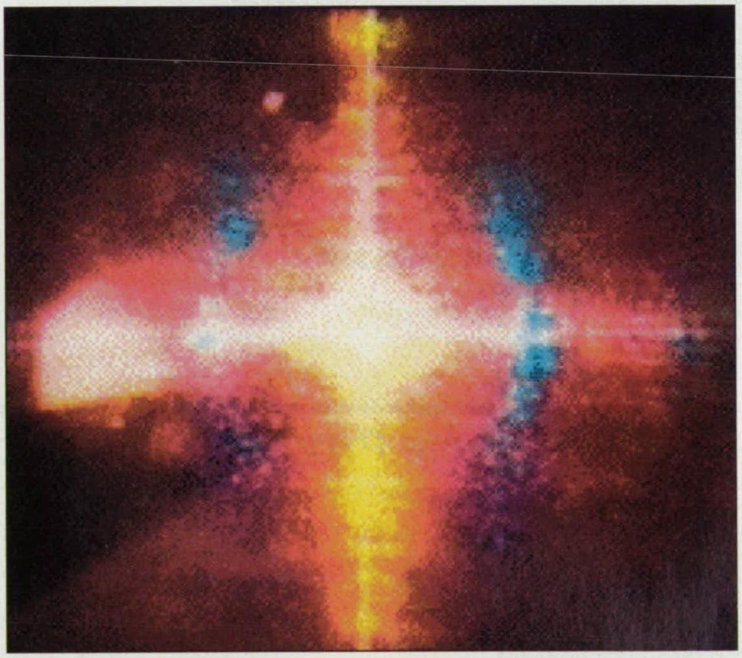


Figure 1. **Lasing emission** from the first electrically injected visible-light vertical-cavity surface-emitting laser (VCSEL).

VCSELs emitting in the near-infrared (near 860 nm) have been available for several years; however, their broad application has been hindered by limited output power and poor efficiency. New research advances have contributed to overcoming these barriers by developing advanced processing schemes for fabrication of the VCSELs as well as precision epitaxial growth methods to maintain high reflectivity in the distributed Bragg reflector (DBR) mirrors while grading the aluminum and gallium concentrations between alternating mirror layers so as to reduce the electrical barriers at the semiconductor mirror interfaces. These advances have facilitated top-surface-emitting VCSEL device demonstrations where threshold voltages of less than 1.5 V and conversion efficiencies nearing 16% have been realized.

On an entirely separate front, recent work in the indium-aluminum-gallium-phosphide (InAlGaP) material system has enabled the realization of VCSEL devices that emit at visible wavelengths (Figure 1). This innovation is expected to lead to greatly expanded applications for VCSEL technology, which was previously limited to near-infrared wavelengths. The visible VCSEL is grown over a commercially available GaAs substrate using metallorganic chemical vapor deposition. Alternating quarter-wavelength-thick layers of AlAs and AlGaAs (Figure 2) create the semiconductor mirrors that form the Fabry-Perot cavity. The light-emitting heart of these devices is the optical cavity composed of several 10-nanometer-thick layers of alternate compositions of InAlGaP. By varying the thickness and mole-fraction of each element of the quaternary alloy in the active region, a series of quantum wells is created in which composition, lattice mismatch (differences in the equilibrium atomic lattice spacings of the quaternary materials), and precise layer thicknesses determine the allowed energy states of electrons and holes, and thus the emission wavelength.

Critical to the realization of these devices was direct experience in tuning the electronic and optical properties of lattice-mismatched epitaxial heterojunction layers resulting from pioneering work on strained-layer semiconductors. By employing strained-layer semiconductors to shift the bandgap of the materials, the team obtained continuous-wave room-temperature emission at wavelengths from 691 nm to 628nm. Also critical was precise control of the growth conditions, to create a gain medium that emitted light at the precise frequency to match the resonant frequency of the Fabry-Perot cavity.

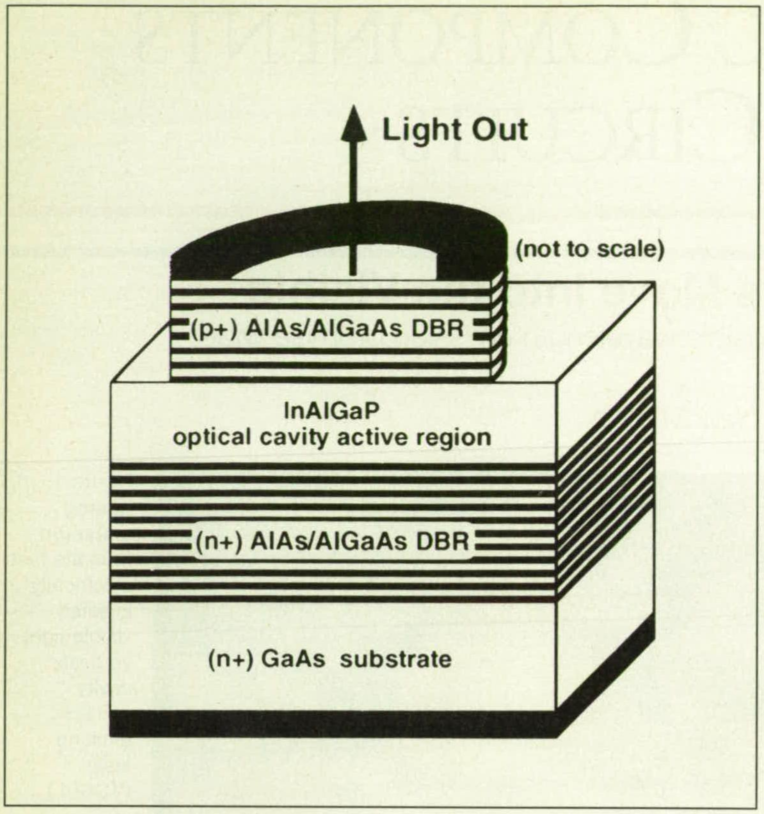


Figure 2. Schematic of the **red VCSEL** lasing structure.

In addition to potential applications for visible displays, this recent advance should enable applications for VCSELs as low-cost print heads for laser printers, as sources for low-cost, rugged, plastic-fiber-based optical networks, and even as potential replacements for gas-laser-based bar-code scanners at supermarket checkouts.

This work was done by Richard P. Schneider, Kevin L. Lear and Del Owyoung of **Sandia National Laboratories**, *a participating member of the Alliance for Photonic Technology. For further information* ***write in 100*** *on the Reader Information Request card, or contact Del Owyoung at (505) 844-5481.*

A patent on this work has been applied for. Inquiries about commercialization through licensing or CRADAs should be addressed in writing to Angelo Salamone, 10520 Research Rd. SE, Albuquerque, NM 87123-1380, or alternatively to the office of the Alliance for Photonic Technology, 851 University Blvd. SE, Bldg. 1, Suite 200, Albuquerque, NM 87106-4339.

SEED-VCSEL Optical Processor Prototype

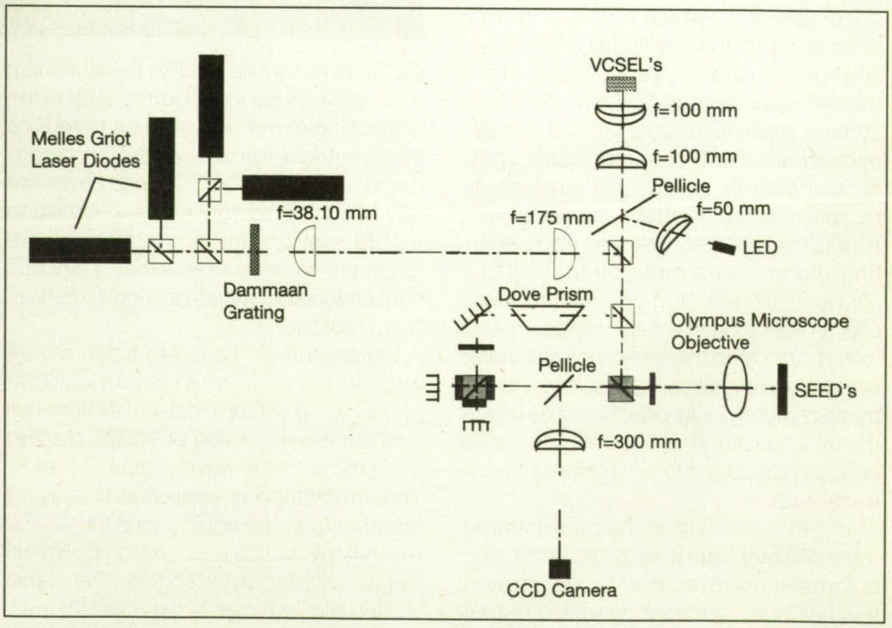
Integrated symmetric self-electro-optic-effect devices and vertical-cavity surface-emitting laser arrays perform general-purpose computing.

Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

Future Air Force signal-processing systems will require enormous amounts of digital computing power. The need for completely reprogrammable radar signal-processing systems in particular has been recently emphasized to allow modifications to be easily made via software upgrades.

One advanced processing approach under investigation involves the use of densely populated arrays of optoelectronic switches interconnected by bundles of large numbers of information-carrying light rays. Millions of rays per bundle are possible, each carrying digital information at greater than gigahertz rates. In the analogous electronics case, several hundred electrical bus lines carrying information at several dozen kilohertz is the practical limit. Hence there is a theoretical 100,000,000-to-1 throughput advantage for optical interconnects.

Past SEED-based optical computing approaches used large, power-hungry external lasers and inefficient fan-out optics to power the switch arrays, and fixed optical masks to determine the static processing function. Extending previous in-house work on optical memories, this recent novel processor demonstration experiment used VCSELs (vertical-cavity surface-emitting lasers) to trigger SEED (self-electro-optic-effect device) optical switch arrays. Such arrays of microlaser devices for the first time aid in building a



The **optical train** of the reprogrammable optical computer prototype using SEEDs and VCSELs. Nonpolarizing beamsplitters are indicated by clear boxes, polarizing by shaded boxes. Shaded rectangles indicate quarter-wave plates.

reprogrammable, efficient, compact and high-speed computing system.

In this scaled-down system experiment, four bits of information stored in four rows of an optical SEED array were scrolled row-to-row by four 850nm laser diodes while a four-by-eight array of VCSELs input new data and control bits. In this fashion reprogrammable, general-purpose computing including digital signal processing can be accomplished. This primitive first-generation system ran at 30 kilohertz, controlled by the 100+ microwatt VCSELs. In the future more efficient switch arrays and higher-power VCSELs will allow gigahertz systems to be built. Also, the SEEDs used were first-generation optoelectronic switch devices, performing a simple latching function. The use of more complex so-called "smart-pixel" arrays, combining the exceptional logic capabilities of electronics with the great interconnect power of optics, undoubtedly in a wafer-scale integration or multichip module electronic architecture, will enable digital signal processors with extraordinary computational capabilities to be fabricated in 5 to 10 years. The mating of photonic VCSEL technology to advanced optoelectronics thus represents a significant insertion of photonics technology into practical defense and commercial systems. Commercial offshoots of this technology may eventually make current electronic computing approaches obsolete.

Inquiries concerning rights for the commercial use of this technology should be addressed to **Rome Laboratory**, *Office of the JA, Griffiss Air Force Base, NY 13441. The SEED-VCSEL processor was developed by J. Battiato, R. Bussjager, and P. Cook of Rome Laboratory, and M. Murdocca and T. Stone of Rutgers University. No further information is available.*

Vacuum UV and X-Ray Free-Electron Laser Components

High-brightness electron beams and high-gain harmonic generation form the basis for short-wavelength coherent radiation sources.

Brookhaven National Laboratory, Upton, New York

Considered by many to be the fourth-generation synchrotron light sources, free-electron lasers (FELs) provide laser-like coherence and peak power of several gigawatts at short synchrotron wavelengths. In addition, such FELs offer the possibilities of very short pulses, down to 100 femtoseconds or shorter. Work being done at the National Synchrotron Light Source (NSLS) department utilizes the Accelerator Test Facility (ATF), a linear accelerator (linac) and laser complex capable of producing high-brightness electron beams and high-power laser pulses synchronized with the electrons.

One component needed for a successful UV FEL is a laser-photocathode RF gun. It generates a high-current low-emittance beam by irradiating a high-quantum-efficiency metal cathode in the presence of very-high-intensity RF electric

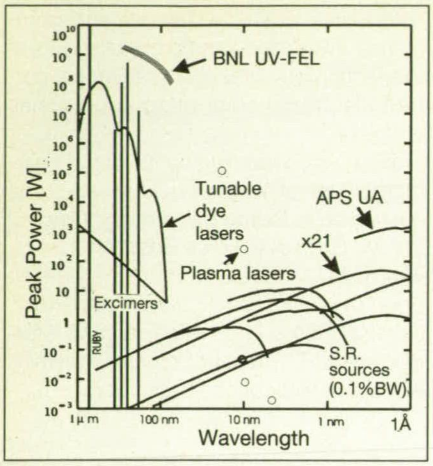


Figure 1. **Peak-power vs. wavelength plot** of some radiation sources shows the void to be filled by short-wavelength free-electron lasers and the proposed UV FEL performance.

fields. The generation and careful manipulation of such beams are an area of intense activity in accelerator physics, viewed by many as the key to short-wavelength FELs.

Free-electron laser experiments on the ATF include work on a visible-wavelength FEL oscillator and high-gain harmonic generation. These systems use novel superconducting undulators providing a high field and very low magnetic-field error.

The FEL harmonic-generation principle is shown in Figure 2. The undulator has three distinct regions. The seed radiation, in this experiment from a CO_2 laser, is injected into the modulator section, which is resonant to its wavelength. The energy-modulated electron beam is bunched magnetically in the dispersive section. The bunched beam radiates coherently in the next undulator section, now resonant at the third harmonic of the seed radiation. This radiation is amplified exponentially up to saturation, and then beyond saturation, by a tapered undulator section.

This experiment emulates the UV FEL physics at a longer wavelength. Multiple harmonic generation may be the best way to build an x-ray free-electron laser for a number of reasons. First, it avoids the difficulty of building x-ray resonator mirrors. The availability of high-power seed lasers makes the necessary undulator short in comparison with some FEL schemes, and the radiation bandwidth and wavelength stability are superb.

Using these techniques, the department is designing an accelerator-based UV radiation source that will provide picosecond and subpicosecond pulses of coherent UV radiation for wavelengths from 300 to 75nm. The pulsewidth will be variable from about 7 picoseconds to less than 200 femtoseconds, with pulse repetition rates as high as 360Hz and peak pulse power of the order of 1 gigawatt in a 10^{-4} bandwidth.

The UV FEL electron beam is generated by the laser photocathode RF gun already described, accelerated to 300MeV by a linac and then sent to an undulator. The radiation is generated by a tunable Ti-sapphire laser, multiplied by conventional techniques to the visible or near-UV. Then, using the high-gain harmonic generation technique, vacuum UV (VUV) radiation is generated and amplified. The radiation pulse length and the intensity-vs.-time profile can be adjusted at the seed laser.

This proposed FEL will provide high-peak-power VUV radiation with the mode structure, bandwidth, and frequency stability of an input seed laser. The peak power of this source makes it ideal for research in dilute samples, such as the gas phase, surface adsorbates or transient species such as radicals produced in a molecular-beam interaction. The narrow bandwidth and tunability are excellent for resonant processes such as threshold spectroscopies and the study of excited states. The short pulse and intensity programmability are suited to relaxation and excitation processes and coherent control of quantum dynamics, and could make possible new avenues of inquiry in time-resolved studies in diverse fields including chemical, surface and solid-state physics, biology and material science.

Two Cooperative Research and Development Agreements (CRADAs) have been established between BNL and Grumman Aerospace, one for development of the advanced RF gun, and the second to build the 2-meter-long undulator for the harmonic-generation experiment.

This work is being done by Ilan Ben-Zvi, Kenneth Batchelor, Erik Johnson, Samuel Krinsky, and Li-Hua Yu of the NSLS department and the Center for Accelerator Physics at BNL, and Ira Lehrman of Grumman Aerospace. For further information ***write in 101*** *on the Reader Information Request card.*

Inquiries concerning rights for the commercial use of components and techniques mentioned herein should be addressed to **Brookhaven National Laboratory,** *Office of Technology Transfer, Building 902-C, Upton, N Y 11973.*

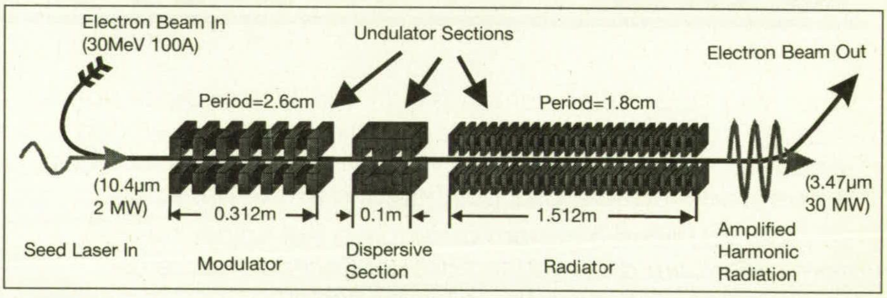


Figure 2. The **high-gain harmonic-generation free-electron laser experiment** uses an electron beam and an undulator to generate and amplify coherent harmonics of a seed laser. The undulator sections are superconducting electromagnets wound on a low-carbon steel form.

Coherent 1-W Unstable Resonator Laser Uses Regrown Lens Train

The URSL principle, successfully applied through a regrown lens train (RLT), is yielding a new breed of high-power coherent sources.

Center for High Technology Materials, University of New Mexico, Albuquerque, New Mexico

The unstable resonator semiconductor laser (URSL) is a new source of spatially coherent power at the 0.1-to-1-watt level. A novel URSL device uses an integrated regrown lens train (RLT) to provide the unstable resonator action. These RLT lasers can be fabricated for different wavelengths, including the important 920-980nm range, where laser pump sources

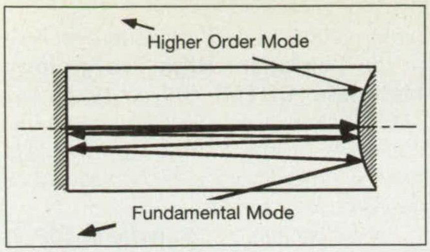


Figure 1. **Unstable resonator principle** is shown: higher-order (off-axis) modes are rapidly lost from the laser cavity.

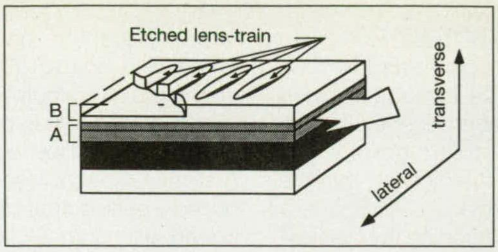


Figure 2. After lens etch, the **integrated lens train in the secondary part (B) of the waveguide** in a RLT laser provides divergence.

are needed in Er-doped fiber amplifiers, frequency doublers and fiber upconversion lasers.

In a generic unstable resonator laser (Figure 1) the optical mode is made to diverge slightly as it travels through the laser cavity. This divergence can be achieved by curving one of the mirrors, as shown in the figure, or by alternative approaches. Higher-order (off-axis) modes diverge rapidly and pass out of the laser cavity, so the unstable resonator discriminates in favor of fundamental-mode operation.

The advantages of the URSL can best be understood by examining the limitations of the conventional Fabry-Perot (FP) type of semiconductor laser. In this laser, single-spatial-mode operation can be obtained only for narrow beamwidths, which result in a high power density at the facet. Therefore the output power is typically limited by the onset of facet damage. If wider beamwidths are used, then the power density is lower, but several lateral modes occur. So the FP semiconductor laser can provide either good spatial coherence or high power, but not both.

In the unstable resonator laser, higher-order spatial modes incur a higher round-trip loss (see Figure 1). This means that the onset of lasing for the higher-order modes, and thus the loss of spatial coherence, is shifted to higher power levels. Furthermore, much larger laser stripe widths can be used, allowing high output power levels, while avoiding high power densities at the facet. So the URSL laser offers high power and spatial coherence together in the same device.

A novel URSL approach is shown in Figure 2. In this device the lasing mode is shared between two parts of a "double" optical waveguide. The main part (A) is a conventional quantum-well gradient-index separate carrier heterostructure (GRINSCH) design that provides gain and transverse waveguiding for the lasing mode. The second part of the waveguide (B) is located above the main part and causes the lasing mode to diverge laterally. This divergence results from a lateral variation of effective refractive index that is achieved by integrating diverging "lens-like" elements into part B of the waveguide.

The epitaxial layers of GaAs, AlGaAs and strained InGaAs that form the laser structure are grown by metallorganic chemical vapor deposition (MOCVD) in two steps. In the first step the lower cladding and GRINSCH active regions are grown, terminating the structure with a thin GaAs layer. The wafer is removed from the MOCVD reactor and "lens" elements are etched into the thin GaAs layer. Figure 2 is a schematic of the wafer after the lens etching step. The wafer is then returned to the MOCVD reactor for the second growth, in which the upper cladding and p-side contact layers are added. The sub-

sequent processing of these wafers into gain-guided wide-stripe lasers follows a conventional sequence. It should be noted that the RLT laser fabrication technology uses standard photolithography and MOCVD procedures, indicating that the laser is manufacturable.

The divergence offered by the "lenses" can be large, and round-trip magnifications of more than 10X have been achieved. The technique has created lenses with sufficient divergence to fill a 170-µm-wide stripe with the fundamental lateral mode. The current "best" RLT design emits 1.01W of power with a differential quantum efficiency of 58.6% (measured using 10-80µsec pulses at 1% duty cycle). This output can be focused to a spot size that is only 1.2X that of a diffraction-limited (perfectly coherent) laser. A slightly different laser design has produced a peak output power of about 2 W pulsed, with a far-field lobe width of only 3X the diffraction-limited width. At present an evaluation of bonding technologies promises to enable higher-power continuous-wave operation of the RLT lasers.

This work was done by Stephen D. Hersee, Swami Srinivasan and Alan H. Paxton (also of US Air Force Phillips Laboratory, Kirtland AFB, Albuquerque, NM) at the **Center for High Technology Materials (CHTM)**, *University of New Mexico, Albuquerque, New Mexico. CHTM and USAF Phillips are R&D participants in the Alliance for Photonic Technology, Albuquerque, New Mexico.*

For further information ***write in 102*** *on the Reader Information Request card. Alternatively, inquiries concerning this device may be directed to Dr. Hersee at (505) 277-1358 or to the Alliance for Photonic Technology, 851 University Blvd. SE, Bldg. 1, Suite 200, Albuquerque, NM 87106-4339; (505) 272-7001.*

Diode Laser Logic (DLL) Devices for All-Optical Signal Processing

Integrated Q-switched lasers and photodetectors form a complete logic family for use in smart pixels.

Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

The advent of the photonic switch is the first step toward all-optical signal processing. New diode laser logic (DLL) devices presently under development consist of monolithically integrated multi-quantum-well semiconductor lasers with intra-cavity modulators electrically connected to photodetectors. DLL presents a full family of logic gates with high fanout and on/off contrast ratio including adjustable width for the input-output hysteresis. Because of the special features of the new logic family, optical binary adders and crossbars can be implemented with just one gate. In addition, the differential input used by self electro-optic effect devices (SEEDs) can also be implemented with DLL.

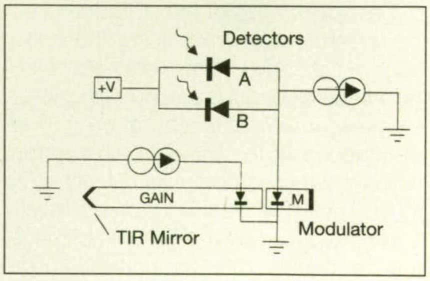


Figure 1. An **optical OR gate** using diode laser logic.

Figure 1 shows an OR gate as an example. The laser cavity has a total internal reflection (TIR) mirror at one end to improve the efficiency; in other designs, this TIR mirror is replaced with a flat mirror for access to the laser output. The modulator between the gain section and the flat 34% reflective mirror on the right-hand side controls the lasing threshold current of the cavity; the threshold current depends exponentially on the reverse bias voltage. The integrated current source (a carbon resistor or FET) reverse-biases the modulator and quenches the laser. Light incident on either photodetector produces photocurrent sufficient to satisfy the current source, forward-bias the modulator and activate the laser. The current source is not required for most of the other logic functions.

Figure 2 (page 25) has a typical linear and logarithmic plot of the emission spectra from an OR gate with external silicon photodetectors; the logic 0 and 1 states are shown. Typically, the lasers are 4 X 100µm in size and the modulators are 4 X 4µm. A current source of 1

µA is limited to reverse-bias voltages of about -4 volts.

The DLL family is expected to be most suitable for digital optical processing and communication applications. Present dual-use applications under development include packet switching, ATM switches, all-optical adders and optical crossbars. In addition, they are a good choice for the optical transmission of data between electronic chips and boards.

This work was done by M. A. Parker, S. I. Libby, J. S. Kimmet and P. D. Swanson (NRC Fellowship) in the Air Force Photonics Center, Surveillance and Photonics Directorate, **Rome Laboratory**, *Griffiss Air Force Base, New York. No further information is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to Rome Laboratory, Office of the JA, Griffiss Air Force Base, NY 13441.

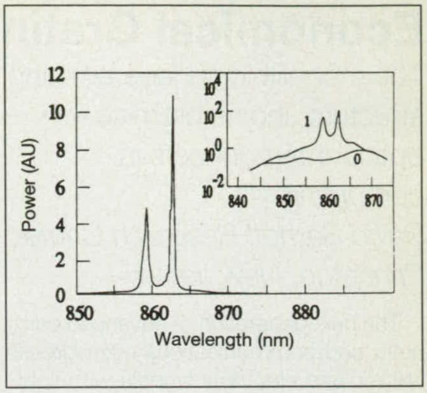


Figure 2. **Emission spectra** from the OR gate. The inset is a semilog plot with the logic states shown.

PLZT/ITO Electro-Optic Phase Grating

A diffraction-limited design for a spatial light modulator reduces the switching voltage.

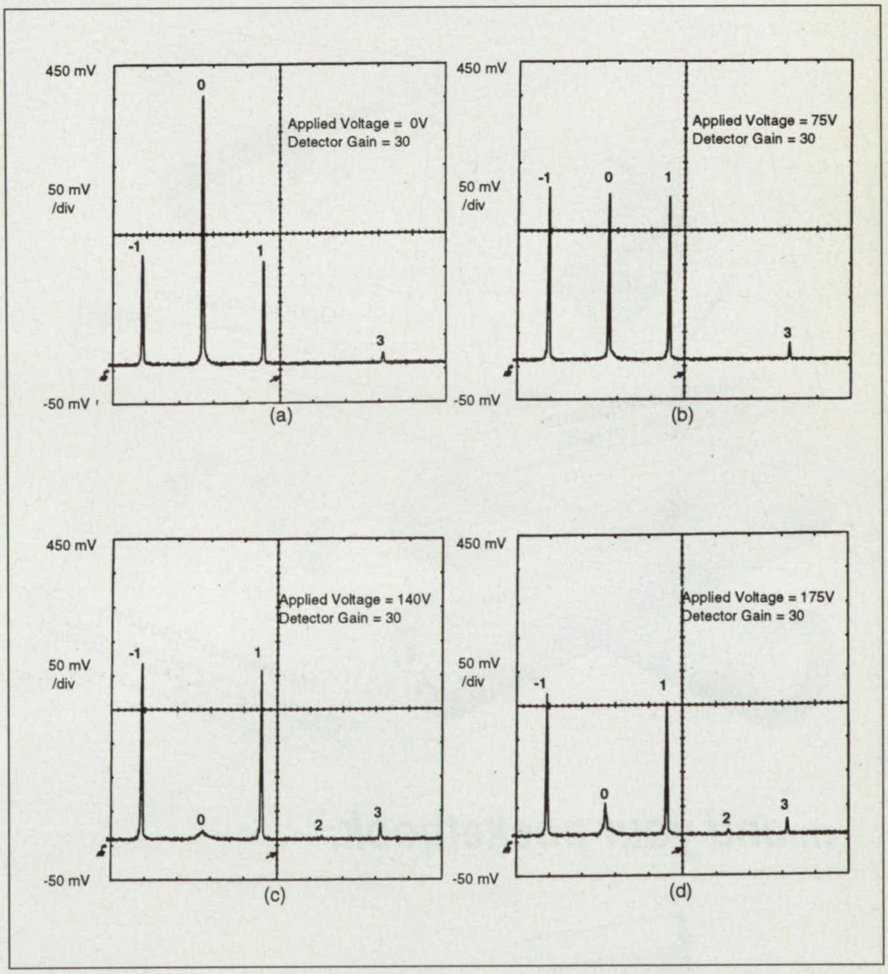
Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

Existing commercial electro-optic spatial light modulators implemented in lead lanthanum zirconate titanate (PLZT) ceramic have relied upon standard polarization-rotation-based amplitude modulation schemes. Such designs require a polarizer/analyzer pair and operating voltages capable of inducing a half-wave phase shift over the entire optical beam aperture.

Two-sided electrode fabrication to increase the electro-optic interaction length of the devices reduces the switching voltage of present commercial PLZT spatial light modulators. Yet even with the increase in interaction length provided by these designs, the minimum switching voltage of commercial PLZT polarization-rotation-based spatial light modulators is 350 volts.But a new diffraction-based spatial light modulator utilizing transparent indium tin oxide (ITO) as the electrode material yields a switching voltage of 140 volts. The electro-optic interaction length for such a PLZT/ITO phase grating has been conservatively estimated as 75 microns.

The figure presents the diffraction pattern of the PLZT/ITO electro-optic phase grating for a sequence of applied voltages. At zero applied voltage, the intrinsic diffraction pattern of the ITO surface electrodes is present. The intrinsic diffraction pattern could be eliminated through the utilization of appropriate index-matching coatings. As the applied voltage is increased, the optical power in the zero-order diffraction mode is reduced. The zero-order mode is essentially switched off at 140 volts.

Previous diffraction-based spatial light modulator designs have utilized lithium niobate as an electro-optic material. The switching voltage of 1650 volts for the lithium niobate design is an order of magnitude greater than that for the PLZT/ITO electro-optic phase grating.



Transmitted **Fresnel diffraction patterns** of the electro-optic PLZT/ITO phase grating: (a) intrinsic ITO electrode phase grating (i.e., V=0); (b) V=75; (c) V=140; (d) V=175.

This work was done by Dr. Pierre J. Talbot of the Photonics Center, **Rome Laboratory**, *Griffiss AFB, New York, and Dr. Qi Wang Song of Syracuse University. No further information is available. Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Rome Laboratory, Griffiss AFB, New York 13441.*

Economical Grating-Surface-Emitting Lasers and Arrays

The monolithic surface-emitting structure shows promise for optical interconnects in computing.

David Sarnoff Research Center, Princeton, New Jersey

The next generation of advanced computer and communications microcircuits will replace electrical signals with lightwaves at the chip level. To be effective, the light sources for these circuits should emit from a semiconductor surface layer rather than from the edge, as conventional laser diodes do. A surface-emitting structure enables the monolithic integration of the laser with optical and electronic devices, and therefore has application in optoelectronic integrated circuits used for computer optical interconnects.

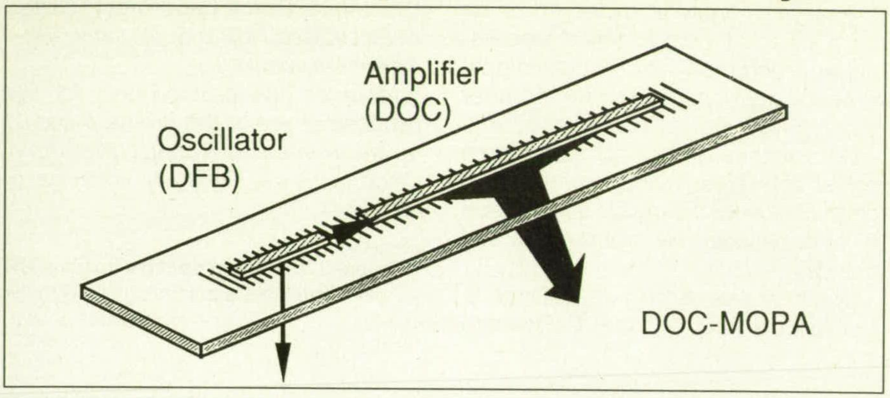


Figure 1. Sketch of the **GSE Distributed Out-Coupled Master-Oscillator Power Amplifier (GSE-DOC-MOPA) laser**. Signal generated in oscillator is amplified and out-coupled in the amplifier. Incorporation of wavelength-tunable section permits beamsteering.

Monolithic grating-surface-emitting (GSE) semiconductor lasers use Bragg grating structures as cavity reflectors for optical feedback, and in this respect differ both from conventional edge-emitting lasers (feedback exclusively from cleaved facets) and from edge-emitting distributed feedback (DFB) lasers (feedback from two cleaved facets combined with that from a Bragg grating). Gratings also provide output coupling needed to extract information from a chip; the degree of out-coupling depends on the detailed fabrication from the grating structure.

GSE lasers comprise a family of devices including (1) monolithic discrete GSE lasers, (2) master-oscillator-power-amplifier (MOPA) devices (Figure 1), and (3) GSE laser arrays of these devices.

The unique fabrication process of GSE lasers leads to several advantages and features; gratings are patterned either by holographic exposure of photoresist or E-beam exposure of resists such as PMMA or PB-TMSS. Unlike vertical-cavity surface-emitting lasers, for which grating layers may be epitaxially grown, the emitted power can be high while single-spatial-mode beam quality is maintained. Monolithic integration of GSE lasers with high-speed electronic circuitry is at an advanced stage of research development (Figure 2, page 27). GSE laser design permits the use of full wafer processing techniques, thereby significantly reducing overall fab-

rication costs as compared with the labor-intensive cleaving, mounting, and testing procedures required for conventional edge-emitting semiconductor laser chips.

Application will dictate emission wavelength. Operation has been demonstrated at 1.55 µm as well as the range 0.85-0.98 µm. Shorter wavelengths provide the advantage of monolithic integration with conventional-design-rule high-speed GaAs logic devices, which are needed for near-term fiber optic interconnects. These may, for example, be located in the backplane of next-generation computers.

Longer wavelengths, at and beyond 1.55 µm, feature the advantage of eye safety, which is desirable for free-space interconnection computing architectures. The coherent light, high in beam quality, also provides the option of optical beam-steering. Processors will be able to communicate selectively with other units by redirecting their multi-gigabit/second light beam to the appropriate partner, affording greater data rates by taking advantage of the spatial bandwidth of the free-space medium.

GSE lasers have shown output powers in excess of 300 mW continuous wave (CW) in a single wavelength with high beam quality. These lasers demonstrate the performance required for laser-based communications systems. Two-dimensional arrays have shown output powers of 3W CW and more than 30 W (3.5 kW/cm^2) in pulsed operation of 100-nanosecond pulses at a 10-kHZ repetition rate. Pulsed power densities exceeding 1 kW/cm^2) are required for pumping solid-state lasers for laser radar applications. Other applications include free-space optical communications, ranging and fusing, optical recording, and optical printing.

This work was done by Dr. Joseph H. Abeles and associates at the **David Sarnoff Research Center**. *Ballistic Missile Defense Organization funds David Sarnoff research in laser radar applications. Partial support was also supplied by the U.S. Air Force, Air Force Systems Command, Phillips Laboratory (PL), Kirtland AFB, New Mexico 87117-6008. For further information,* ***write in 103*** *on the Reader Information Request card.*

Inquiries concerning rights for the commercialization of this invention should be addressed to Joseph H. Abeles, David Sarnoff Research Center, CN 5300, Princeton, New Jersey 08543-5300; (609) 734-2571.

NASA's Report SPINOFF '93

If you want to find out how NASA technology has been applied by private industry and has resulted in the development of commercially available products or services, you may wish to request a copy of this report by writing in **#391**.

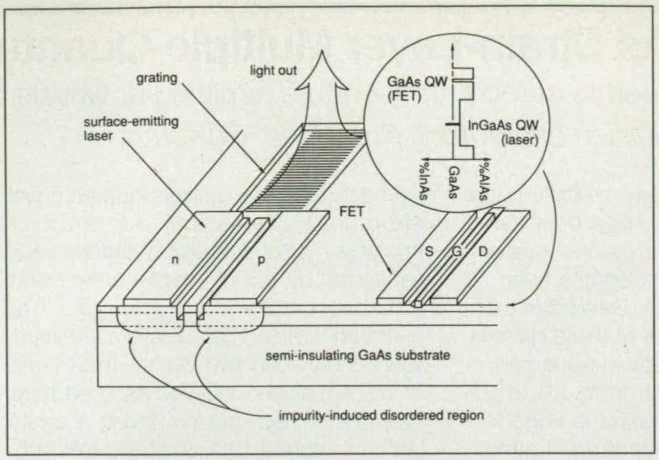


Figure 2. Schematic showing **details of planar monolithic integration** of GSE lasers with high-speed GaAs FET circuits. Emission at 980 nm using strained InGaAs quantum-well lasers' active regions allows FET and laser to operate independently.

In_xGa_{1-x} As Strain-Layer Multiple-Quantum-Well Laser Diodes

These devices operate at room temperature, emitting at wavelengths near 1.8µm.

NASA's Jet Propulsion Laboratory, Pasadena, California

$In_xGa_{1-x}As$ strain-layer multiple-quantum-well laser diodes have been fabricated on InP substrates and demonstrated to emit at wavelengths near 1.8 µm at room temperature. By suitable modification of the structure of these devices, it should be possible to achieve operation at any wavelength from 1.6 to 2.5 µm: this wavelength range is important in lidar and in remote sensing of atmospheric gases.

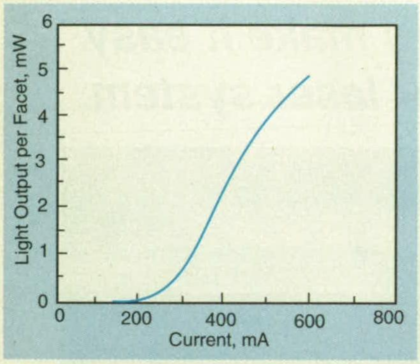


Figure 1. This **Light-Output-vs.-Current Curve** was obtained from measurements on a prototype laser diode 10µm wide and 1.0mm long.

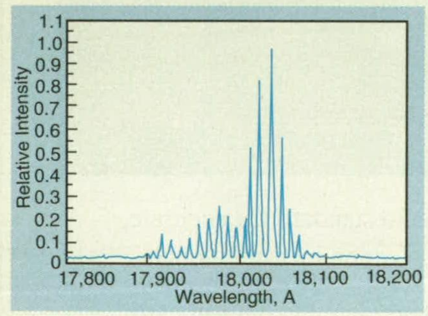


Figure 2. This **Emission Spectrum** was produced by a prototype laser diode 500µm long, at a current 1.5 times threshold.

The strain-layer multiple-quantum-well structure includes four 3.5-nm-thick $In_{0.75}Ga_{0.25}As$ strained quantum wells separated by 6.5-nm-thick barrier layers of lattice-matched $In_{0.53}Ga_{0.47}As$. The quantum-well and barrier layers are sandwiched between two 60-nm-thick layers of lattice-matched InGaAs. As used here, "lattice-matched" means having a crystal lattice matched to that of the InP substrate.

The InGaAs layers are sandwiched between two 150-nm-thick layers of InGaAsP, in which the gap between the valence and conduction electron-energy bands ("bandgap," for short) corresponds to a wavelength of 1.3µm for a photon of equivalent energy. The InGaAsP layers are sandwiched, in turn, between the InP substrate and an InP cladding layer. There is also a layer of InGaAs atop the InP cladding layer.

The strain in the quantum-well layers affects the bandgap in them and thereby affects the laser wavelength. Thus, the structure of this device or a suitably modified version is chosen to establish the specified strain and thereby obtain the desired wavelength.

Prototype wafers to demonstrate this laser-diode concept were made by atmospheric-pressure metalorganic vapor-phase epitaxy on a (100)-oriented, n-doped InP substrate. The epitaxial layers were grown by use of trimethyl gallium, trimethyl indium, arsine, and phosphine. Hydrogen sulfide and diethyl zinc were used for the n and the p doping, respectively. The entire epitaxial growth was carried out without interruption, at a temperature of 650 °C.

Ridge waveguide structures were fabricated by removing the top InGaAs layer and etching the InP cladding layer. The wafer was then processed via standard deposition of dielectric material, photolithography, and deposition of metal contacts. The wafer was then cleaved into laser-diode bars of various lengths to provide laser resonant cavities of various lengths.

The laser diodes were tested at a temperature of 20 °C in pulse operation at a repetition rate of 1 kHz. The threshold currents and output powers of these devices were measured (see Figure 1). From these measurements, the threshold current density and differential external quantum efficiency were found to be 2.5 kA/cm^2 and 5 percent, respectively. Lower threshold current densities and greater quantum efficiencies should be achievable by use of multiple-quantum-well structures containing barriers of greater height, and by use of lower concentrations of p dopant. Figure 2 shows the emission spectrum of one of the laser diodes, featuring a peak at a wavelength of 1.8040µm.

This work was done by Siamak Forouhar, Anders G. Larsson, Alexander Ksendzov, and Robert J. Lang of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 77*** *on the Reader Information Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

William T. Callaghan, Manager
Technology Commercialization
(M/S 79-23)
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Refer to NPO-18827, volume and number of this Laser Tech Briefs *issue, and the page number.*

Improved Electro-Optical Switches

Beams of light are switched rapidly, with no moving parts.

Lewis Research Center, Cleveland, Ohio

Improved single-pole, double-throw electro-optical switches that operate in switching times less than a microsecond are being developed for such applications as optical communication systems and networks of optical sensors. Unlike mechanically actuated fiber-optic switches, these and other electro-optical switches contain no moving parts. In comparison with some prior electro-optical switches, these electro-optical switches are simpler and can be made to operate with smaller optical losses.

The active switching element in one of the improved switches is a rectangular parallelepiped crystal of bismuth germanium oxide, bismuth silicon oxide, or other material that has the following electro-optical characteristics (see Figure 1): (1) In the

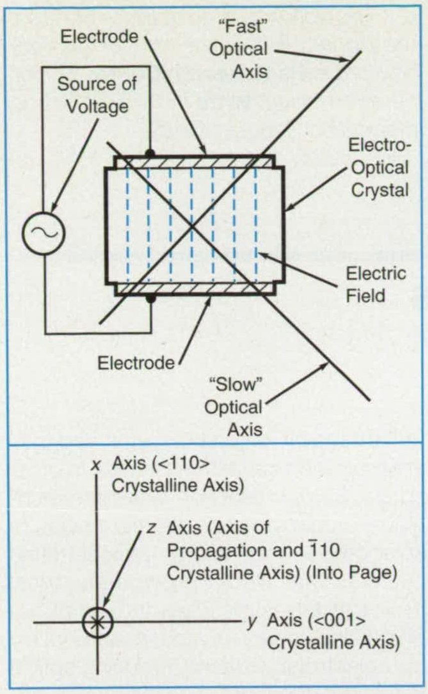


Figure 1. The **Optical Axes and Electric Field** in the crystal are oriented perpendicular to the direction of propagation of light in the crystal.

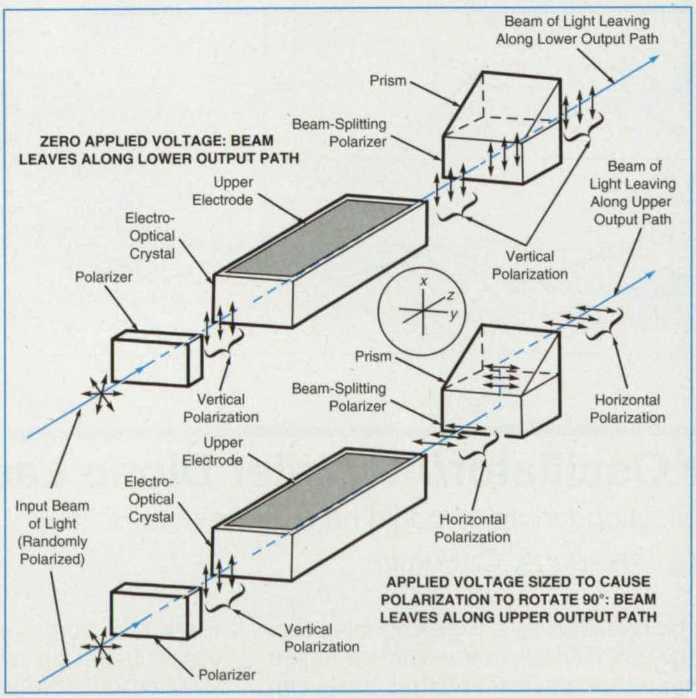
absence of an applied electric field, it does not exhibit birefringence. (2) With respect to the propagation of light along one of its axes, it exhibits birefringence proportional to the strength of an electric field that is applied along an axis perpendicular to the direction of propagation. (3) This birefringence manifests itself in one "fast" axis and one "slow" axis, both perpendicular to the direction of propagation and to each other.

The switch (see Figure 2) can operate on coherent light (e.g., from a laser) or incoherent but nevertheless narrow-spectrum light (e.g., from a light-emitting diode). The beam of light from the source passes through a polarizer, which allows only the vertically polarized part to enter the electro-optical crystal. When no voltage is applied to the electrodes on the upper and lower surfaces of the crystal, there is no electric field; therefore, there is no birefringence, and the beam passes through the crystal with its polarization unchanged. The beam that emerges from the electro-optical crystal enters a beam-splitting polarizer; when its polarization is vertical, as it is in this case, it passes straight through the beam-splitting polarizer and out along the lower one of two output paths.

The "fast" and "slow" axes of the crystal lie at 45° to the vertical axis. The vertically polarized light can be regarded as consisting of two components: one polarized along the "fast" axis and one polarized along the "slow" axis. When a voltage is applied to the electrodes, the "fast"-polarized component propagates through the crystal faster than the "slow"-polarized component, with resultant rotation of the polarization of the light beam. The dimensions of the crystal and the applied voltage can be chosen so that the net rotation is 90°; that is, the light that emerges from the electro-optical crystal is polarized horizontally. In this case, the beam-splitting polarizer directs the beam upward to a prism, which reflects it out along the upper one of two output paths (or other output devices). Thus, by applying a suitable voltage to the electrodes, one can switch the beam from the lower to the upper output path.

If the light from the source is random-

Figure 2. **The Beam of Light Is Switched** from one output path to the other by applying, to the electro-optical crystal, a voltage that causes the polarization of the beam of light to change from vertical to horizontal.



ly polarized, then half of it is lost in passage through the input vertical polarizer. One can prevent this loss by replacing the input vertical polarizer with a subassembly that contains a beam-splitting polarizer, polarization rotator, and beam combiner. These components can be arranged to capture the horizontally polarized part, convert this part to vertical polarization, and combine both parts into one vertically polarized beam, which is fed to the electro-optical crystal.

This work was done by Bruce N. Nelson and Ronald F. Cooper of Geo Centers, Inc., for **Lewis Research Center**. *For further information,* ***write in 9*** *on the Reader Information Request Card.*
LEW-15228

Low-Reflectance Surfaces for Solar Cells

Etched low-angle grooves help recover reflected light.

Lewis Research Center, Cleveland, Ohio

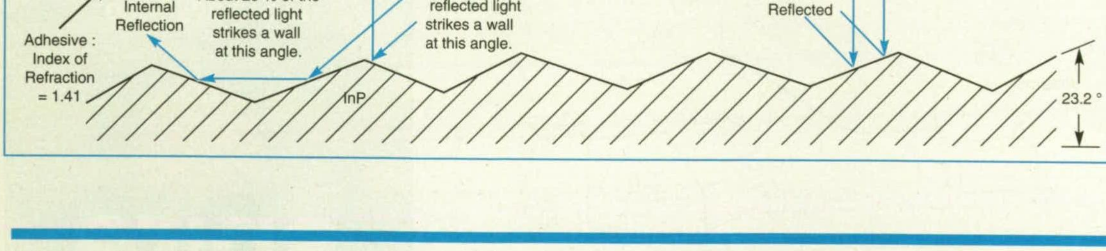
An improved method for increasing solar cell efficiency has potential application for space-based and terrestrial solar power systems and optoelectronic devices. The energy-conversion efficiency of a solar photovoltaic cell is reduced when a portion of the light incident on the surface of the cell is lost by reflection. An antireflection coat reduces this reflection loss but cannot reduce reflection to zero over the entire solar spectrum. Various surface textures, including grooves or pyramids, have been proposed to reduce reflection, but the fabrication of cells with such textures requires complicated processing and often involves decreases of the efficiency, reliability, and yield, along with increases in the cost of manufacture.

In an improved method of increasing the efficiency of cells made of indium phosphide (a high-efficiency, radiation-tolerant solar-cell material), the surface of each cell is textured with low-angle V-grooves. The angle of the grooves is chosen so that the light reflected from the surface of the cell is trapped in the cell cover glass and adhesive by total internal reflection and is thus recovered and reflected back onto the cell (see figure).

The low-angle V-grooves are fabricated by a simple HCl-etch technique, with no requirement for alignment or photoresist masking. In addition to reducing the loss by reflection from the surface of the solar-cell material, the etched grooves can also help to recover light incident on the metal contacts on the surface of the cell, which light is lost on conventional solar cells. The output currents of solar cells made by use of this technique have been demonstrated to be 8 percent greater than those of otherwise identical cells made without the improved surface etch. Greater increases in outputs are expected with further refinements in processing.

This method can be applied to many devices. InP solar cells are highly resistant to damage by ionizing radiation and thus are promising candidates for use in outer space. Similar reflection-reduction techniques could increase the efficiencies of solar cells in solar-energy-concentration systems that would provide electrical power at terrestrial sites. Indium phosphide also serves as a base material for optoelectronic devices, including optical detectors, which are used for a wide variety of applications, including optical-fiber communications. Reduction of reflection losses in such applications would increase the efficiencies of detectors used in them. Similarly, low-angle grooves could be used to reduce surface reflections in devices made of such other semiconductor materials as GaAs.

This work was done by Sheila G. Bailey of **Lewis Research Center** *and Geoffrey A. Landis, Navid Fatemi, and Phillip P. Jenkins of Sverdrup Technology. For further information,* ***write in 4*** *on the Reader Information Request Card. LEW-15612*



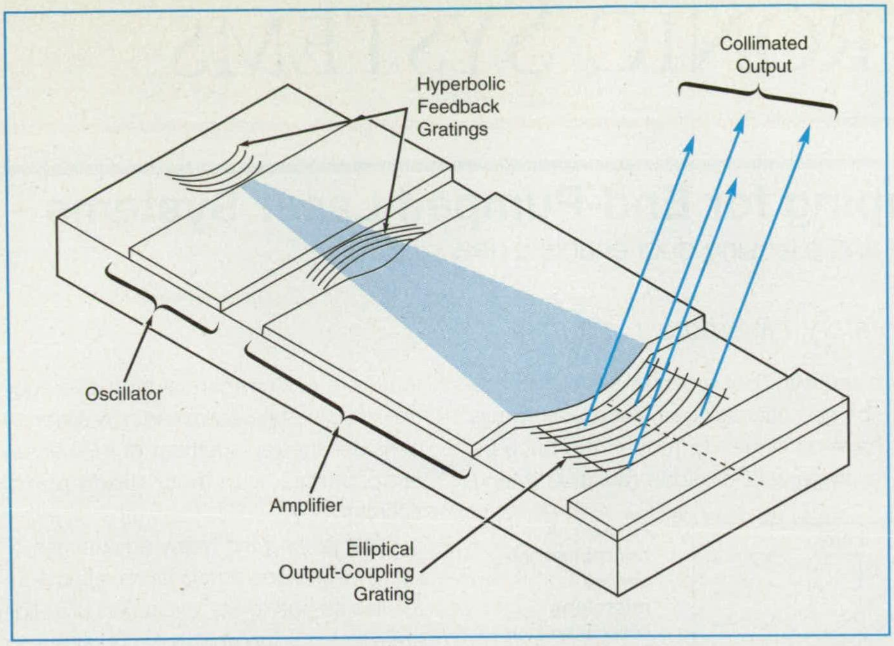
Light Reflected From the V-Grooved Surface is trapped in the cover glass and adhesive by total internal reflection. Thus, the reflected light is redirected onto the surface, and a greater fraction of the incident light is absorbed, producing more electrical energy in the InP solar photovoltaic cell.

Unstable-Resonator Oscillator/Amplifier Diode Laser

Mode-definition and power-amplification functions could be optimized separately.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure shows a proposed hyperbolic-grating, unstable-resonator oscillator/amplifier diode laser that would be fabricated as a single-chip integrated circuit. This device would be based partly on a concept that has been proved in commercial solid-state lasers: using an unstable-resonator oscillator to define the electromagnetic



The **Hyperbolic-Grating, Unstable-Resonator Oscillator/Amplifier** diode laser would produce a single-longitudinal-mode, broad, laterally coherent, diffraction-limited, high-power beam.

mode and, following the oscillator, a traveling-wave amplifier to generate high power. The incorporation of this concept into the design of the proposed diode laser is expected to result in a high-power, laterally coherent, diffraction-limited beam that fills a large output aperture. In addition, the separation of mode-definition and power-amplification functions would enable the separate optimization of each.

The unstable-resonator oscillator would be bounded at its ends by feedback reflectors in the form of hyperbolic surface diffraction gratings. The hyperbolic structure would provide an aberration-free oscillator output diverging from an apparent point source; that is, the low-power output beam of the oscillator would be wide and uniform with coherence along circular wave fronts. The portion of this beam transmitted by the hyperbolic-grating mirror at the broader end of the oscillator would be injected into the power amplifier.

The power amplifier would be energized via an electrical contact separate from that of the oscillator. This power amplifier would operate in a traveling-wave mode and would have a diverging-beam, single-pass geometry, which would suppress the tendency toward self-focusing and the consequent filamentation of the laser beam.

The amplified beam would be directed to an elliptical grating, which would serve as a detuned output coupler. Detuning would suppress spurious reflection of the output beam back into the amplifier. Inasmuch as the amplified beam (with a typical maximum power of 1 W) would be spread over a relatively large area ($>100\times100$ μm^2), power density at each facet of the grating would be relatively low. The spacing and curvature of the elliptical arcs in this grating would be chosen so that the output beam emanating from the surface of this grating would be collimated.

The device would be fabricated in the $Ga_xAl_{1-x}As$ material system. Gratings would be formed by electron-beam lithography, which is as amenable to hyperbolic grating geometries and elliptical grating geometries as it is to straight-line grating geometries. With complete flexibility in the shapes of the gratings, it would also be possible to modify the output-coupling grating geometry to account for thermal lensing and other parasitic effects. The use of surface gratings (as distinguished from other types of gratings or other reflector structures) would make the fabrication process simpler and more reliable than it would otherwise be, in that only a single growth step and a single grating-fabrication step would be needed. No cleaving or etching of facets perpendicular to the broad surfaces would be needed.

This work was done by Robert J. Lang, Michael Mittelstein, Richard C. Tiberio, Siamak Forouhar, and Deborah Crawford of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 62*** *on the Reader Information Request Card.*
NPO-18804

Scalable Diode Pumping for End-Pumped Laser Systems

A microlens, microchannel cooling and a lensing duct enable a new class of diode-pumped solid-state lasers.

Lawrence Livermore National Laboratory, Livermore, California

The average power-performance capability of semiconductor laser diode arrays has improved dramatically over the past several years. These improvements, combined with cost reductions in the fabrication and packaging of diode laser arrays, have continued to reduce the price per average watt of diode radiation. Manufacturers of commercial high-average-power solid-state lasers can now seriously consider the replacement of their flashlamp pumps with laser diode pump sources.

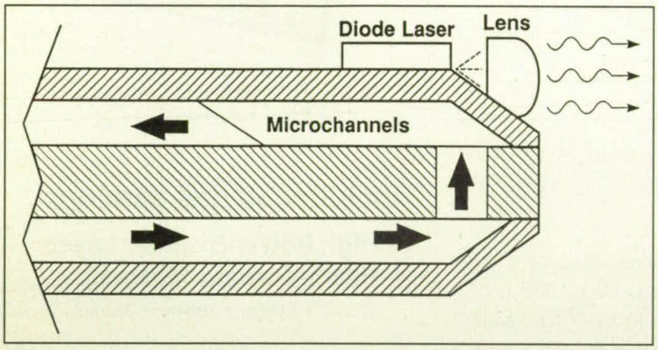


Figure 1. A **microchannel-cooled microlens** collects and collimates the fast-axis radiation from a diode laser used for end-pumping.

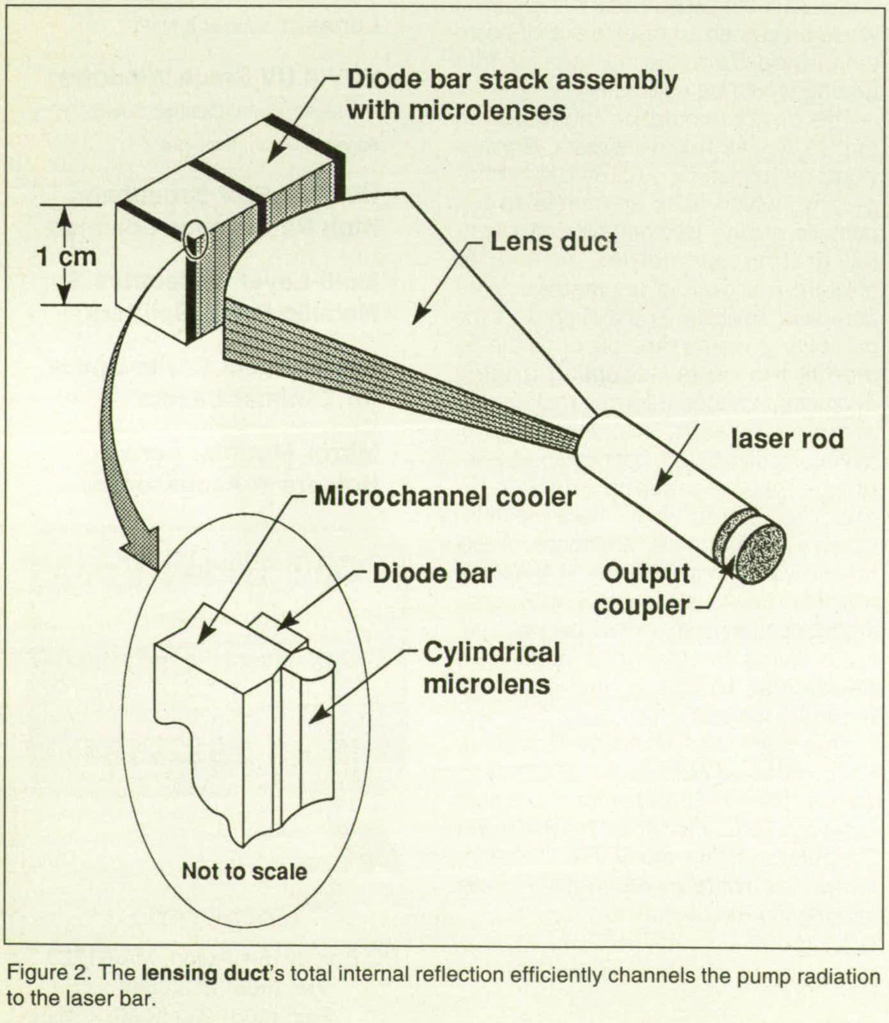


Figure 2. The **lensing duct**'s total internal reflection efficiently channels the pump radiation to the laser bar.

Chief among the many advantages of using laser diode arrays as replacements for flashlamps in the excitation of solid-state lasers is the ability of such arrays to be used in the end-pumping of laser crystals. This capability has significantly expanded the number of ions and transitions that have been demonstrated to be useful as lasants. As the number of lasant ions and accessible transitions has grown, so has the diversity in the wavelength of diode-pumped solid-state laser (DPSSL) systems and the number of applications for which they are being pursued.

At present, DPSSLs are being contemplated and developed for atmospheric and space-based lidar systems, underwater illumination and sensing, wind-shear sensing, remote sensing of chemical species, lithographic processing, medical applications, and electronic and material processing applications. The ability to focus or condense the output from semiconductor diode laser arrays to high intensities is important for the efficient operation of lasers in many of these applications because of the high pump intensities required to efficiently excite the laser ions to useful levels.

One drawback the diode end-pumped architecture has suffered from until now has been the limited number of diode apertures that could be combined into a single focused beam. This has limited the peak and average power-scaling capability of the end-pumping architecture and restricted the number of systems in which it could be usefully implemented. In the past, when peak or average power-scaling was required in a DPSSL it was necessary to use a transverse pump geometry, one in which the diode arrays are placed juxtaposed to the laser crystal and

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essentially flood the crystal with pump radiation. In this approach no attempt is made to combine and focus the output radiation of the diodes into a single spot, and the pump intensity at the crystal is limited to approximately the pump intensity coming off the diode arrays — today at most several kW/cm^2. These low pump intensities have restricted the use of the transverse pump geometry to the Nd ion.

The end-pump geometry, which can generate pump intensities of 100 kW/cm^2, has been aided by the development that allows the simple scaling of the peak and average power capability of this geometry to the kilowatt range. The stumbling block in the development of a scalable diode end-pumping architecture has been the intrinsically low effective radiance of the two-dimensional emitting apertures constructed from a stack of laser diode array bars. The low effective radiance of arrays results from the fact that the diode radiation is generated in a waveguide structure having at least one transverse dimension approximately equal to the radiation's wavelength. This results in a beam of radiation with high divergence angle, on the order of 60° in one dimension, commonly referred to as the fast-axis direction.

The key to overcoming the low radiance in the fast-axis direction is the optical conditioning of the diode radiation from individual bars. A very high-precision cylindrical microlens does just that, and is very low-cost to produce in quantity using a fiber-pulling technique. Figure 1 is a cross-sectional view of a high-average-power laser package which utilizes microchannel cooling to enable 1-cm-long diode array bars to generate 100W of continuous-wave optical output. The radiation, diverging at approximately 60°, is collected and collimated by the cylindrical microlens mounted on the front of the package. After collimation the divergence of the diode light is reduced to 0.6°.

The microchannel-cooled packages can be stacked at a pitch of 10 per cm to form two-dimensional arrays capable of generating average-power pump intensities of 1 kW/cm^2 at the array aperture. In such stacks, as has been seen, the microlens conditioning decreases the fast-axis divergence angle by approximately a factor of 100. It is this decrease and the accompanying ability to focus the radiation to a smaller spot than if no conditioning had been performed that enables the output radiation from large two-dimensional diode stacks to be efficiently delivered to the end of rod lasers.

Figure 2 shows a drawing of an end-pumped rod laser. The radiation from the microlens-conditioned array stack is delivered to the laser rod by a device called a lensing duct. This optical component can be fabricated from any transparent optical material and relies on lensing at its curved input face and total internal reflection on its canted planar faces to efficiently channel the diode pump radiation to the laser bar. The best way to visualize the operation of the lensing duct is to view it as an immersion lens; i.e., its length l, input radius of curvature R, and index of refraction n are related by $l=Rn/(n-1)$. Based on measurements and modeling, the transfer efficiency of the lensing duct for the microlens-conditioned radiation from a 6-cm-X-1-cm diode array aperture (6kW aperture) to a 3.2-mm-diameter laser rod is in excess of 90%.

The advantage of the lens duct over a simple lens is efficiency. Because the diode aperture represents an extended incoherent source of radiation, imaging a large array via a simple lens generally overfills

the input aperture of a small rod many times. With the lensing duct the radiation that would be delivered outside the aperture of the rod can still be efficiently channeled to the rod by reflecting off its canted planar sides.

In summary, two technologies now enable the scalable laser diode end-pumping of rod lasers. These are the ability to build high-density, high-average-power laser diode arrays, and the microlens-conditioning/lensing duct system that enables the outputs of large two-dimensional arrays to be efficiently delivered to the end of rod lasers. To date this technology has been used to build a 100-mJ Q-switched Nd:YLF laser oscillator for use in atmospheric and space-based lidar systems, and a wing-pumped Cr:LiSAF laser using 770-nm AlGaAs laser diode arrays. Presently, the end-pumping technology is being pursued in the demonstration of a 2-mm Tm:YAG laser for medical applications.

One very promising commercial development foreseen to emerge with this technology is in the area of high-average-power DPSSL systems for material-processing applications in which a rod laser technology uses Yb:YAG as the gain element. The high intensities that can be generated with the end-pumping technology offer an opportunity to overcome the deleterious ground-state reabsorption problem of the Yb3+ ion. At the same time, advantage can be taken of the very small thermal power generation parameter of the Yb3+ ion by using the high-average-power capability of the diode laser technology to implement a high-average-power DPSSL system that uses a very simple rod-laser approach. Because such a Yb-based DPSSL produces an output at 1μm which is compatible with fiber delivery, it is receiving much attention from the industrial laser material processing community.

This work was performed in the Advanced Applications Group of the Laser Program under the auspices of the U.S. Department of Energy by **Lawrence Livermore National Laboratory** *under contract W-7405-Eng-48. For further information contact Dr. Ray Beach, L-495, P.O. Box 808, Lawrence Livermore National Laboratory, Livermore, CA 94550.*

Inquiries concerning the rights for the commercial use of the inventions should be addressed to Norma Dunipace of the Technology Transfer Initiatives Program, L-795, P.O. Box 808, Lawrence Livermore National Laboratory, Livermore, CA 94550; (510) 422-5995.

CMOS-Compatible Ultra-High-Resolution Optical Position Sensor

A simple, inexpensive optical position sensor with less than 4 nanometers' resolution has been fashioned from silicon.

Center for High Technology Materials, University of New Mexico, Albuquerque, New Mexico

The detection of small, nanometer-scale transverse positional displacements is increasingly important in a wide area of applications, including mask alignment, photolithography, alignment of optical systems, scanning force microscopy, optical tracking systems and wavefront detection in astronomy. The critical dimension scale of photolithography is approximately half a micrometer today, and projections are that it wil be 0.1 micrometer within the decade. Alignment techniques must be precise to a small fraction of these dimensions. Similarly, optical systems must be aligned to a small fraction of a wavelength. Inexpensive tracking systems with micron to submicron resolution are required for both magnetic and optical data storage systems.

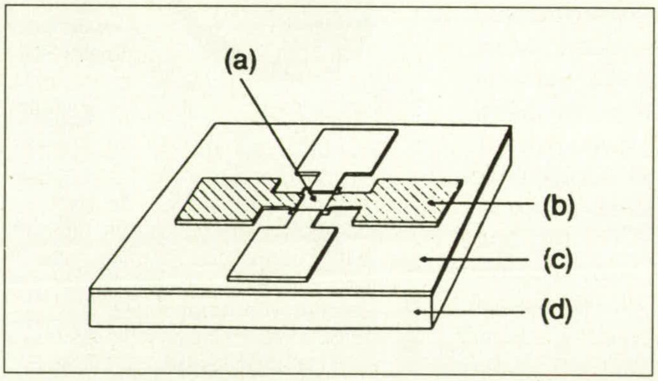


Figure 1. **Position sensor** formed by back-to-back Schottky barriers: (a) gap; (b) Ni metalization; (c) oxide barrier layer; (d) Si (bulk).

Longitudinal interferometers (*e.g.*, Fabry-Perot or Michelson) can monitor position in these applications, but are expensive and delicate. Advantages of optical position-sensing photodetectors include small size, simplicity of use, integratability, low cost and ruggedness. Position-sensitive photodetectors, based on the lateral photovoltaic effect, have been fabricated in a wide variety of semiconductor systems with device gap widths typically on a scale on millimeters to centimeters and resolutions of tens of micrometers. These devices are based on large-area p-n or p-i-n junctions, often with contacts on both sides of the semiconductor.

A new, simple planar back-to-back Schottky-barrier silicon position sensor of 3-to-80-micrometer gap dimensions is sensitive to nanometer-scale position changes. Although the ability to detect a displacement of nanometers or less has been extrapolated, this is the first position sensor to demonsrate nanometer resolution. Unlike most other position-sensitive photodetectors, this device requires contacts to only one side, making it fully compatible with VLSI processing. Thus the device can be combined with signal conditioning and control electronics and does not add any cost to the system. A simple short-circuit photocurrent measurement results in a demonstrated precision of 4 nanometers, limited by vibrations and other environmental fluctuations. The extrapolated resolution, for an optical input power of 1mW, given by detector and amplifier dark noise, is less than 0.25pm/$\sqrt{Hz}$.

The position sensor shown in Figure 1

is a Ni-Si-Ni metal-semiconductor-metal back-to-back Schottky photodiode fabricated on an n-type silicon substrate. Both one-dimensional and two-dimensional structures have been fabricated.

Figure 2 shows a two-dimensional raster scan of an 80 X 80-square-micrometer sensor taken in increments of 2 micrometers, with a laser spot diameter of ~3 micrometers and an incident laser power of 1mW. The absolute values of the current readings from both ammeters were added, normalized and subtracted from unity. The peak in the graph is the null of the sensor, with a single crossover in both directions. The expanded view of the center 2 X 3-square-micrometer region was taken with two piezoelectric transducer drives in increments of 50 and 150 nanometers respectively.

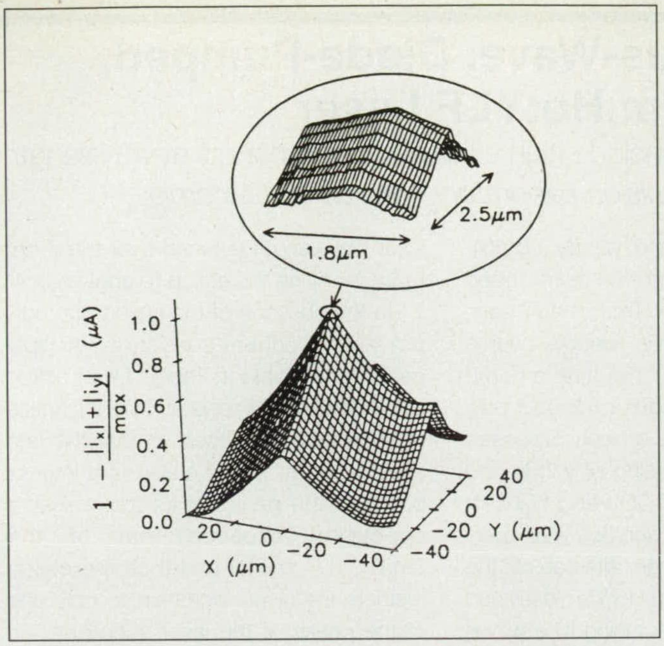


Figure 2. Normalized **position sensitivity** for a 2D 80x80μm^2 sensor. Grid is 2x2μm increments. Inset is of central 2x3μm^2 region in 50-by-150nm increments.

This work was done by Prof. S. R. J. Brueck, K. A. M. Scott, A. K. Sharma, C. M. Wilson, B. W. Mullins and S. F. Soares at the **Center for High Technology Materials (CHTM)**, *University of New Mexico, Albuquerque, New Mexico. For further information* ***write in 106*** *on the Reader Information Request card. Partial support was provided by SRC/SEMATECH, the Naval Research Laboratory and the Air Force Office of Scientific Research. CHTM is an R&D participant in the Alliance for Photonic Technology, Albuquerque, New Mexico.*

Inquiries concerning rights for the commercial use of this invention should be addressed to Prof. Brueck, CHTM, University of New Mexico, Albuquerque, NM 87131, or alternatively to the Alliance for Photonic Technology, 851 University Blvd. SE, Bldg. 1, Suite 200, Albuquerque, NM 87106-4339; (505) 272-7001.

Continuous-Wave, Diode-Pumped, Tunable Tm,Ho:YLF Laser

Unique features include high efficiency and tunability at wavelengths near 2.067 μm.

NASA's Jet Propulsion Laboratory, Pasadena, California

Figure 1 illustrates schematically a continuous-wave thulium-and-holmium-doped yttrium lithium fluoride (Tm,Ho:YLF) laser, the output of which is tunable over a wavelength range of 7 nm near a nominal middle wavelength of 2.067 μm. Tm,Ho:YLF lasers have been proposed for use in remote sensing of winds and in remote sensing of CO_2 and H_2O, of which many strong absorption lines overlap the laser tuning range. Alternatively, the range of a tunable Tm,Ho:YLF laser can be extended by simply tuning to a wavelength between CO_2 and H_2O absorption peaks.

Pump light is supplied by a 500-mW GaAlAs diode laser tuned to a wavelength of 792 nm. The collimated pump beam has an elliptical cross section. To enhance the stability of output in the face of small misalignments and to optimize pumping efficiency, the pump beam is made nearly circular by use of an anamorphic pair of prisms. The beam is then focused onto the input face of the Tm,Ho:YLF crystal. The dichroic coat on this face transmits most of the light at the pump wavelength (792 nm) and reflects most of the light at the output laser wavelength (at or near 2.067 μm).

The laser resonator is that portion of the optical train that lies between the input dichroic face of the Tm,Ho:YLF crystal and an output spherical mirror of 10-cm radius. An uncoated fused-silica Fabry–Perot etalon 0.25 mm thick is placed within the resonator. The output laser wavelength is tuned over the 7-nm range by tilting the etalon to angles up to 7°. In the absence of the etalon, the output laser spectrum consists of multiple peaks attributable to Fabry– Perot action in the Tm,Ho:YLF crystal. The thickness of the etalon is chosen so that the free spectral range of the etalon (the interval between the peaks of its transmission spectrum) exceeds that of the Tm,Ho:YLF crystal and thus the etalon restricts the laser oscillation to only one of the peaks of the laser spectrum. As an additional benefit, this concentration of the available laser gain into one electromagnetic mode makes the laser capable of oscillation at wavelengths farther from the middle of the gain bandwidth.

The output power of the laser was measured as a function of pump power, output wavelength, and temperature of the Tm,Ho:YLF crystal. A maximum output power of 84 mW was measured at an absorbed pump power of 200 mW at a temperature of 275 K, indicating a conversion efficiency of 42 percent. The extrapolated threshold absorbed pump power was found to be 60 mW, and the slope efficiency (increase in output power/increase in absorbed pump power) was found to be 60 percent — believed to be the highest yet reported for a Tm,Ho:YLF laser operating near room temperature.

Figure 2 illustrates the tunability of the laser via rotation of the etalon at a temperature of 256 K. In addition, one can effect fine tuning by adjusting the temperature; the measured rate of change of wavelength with temperature is about $-0.03\ cm{\bullet}K^{-1}$.

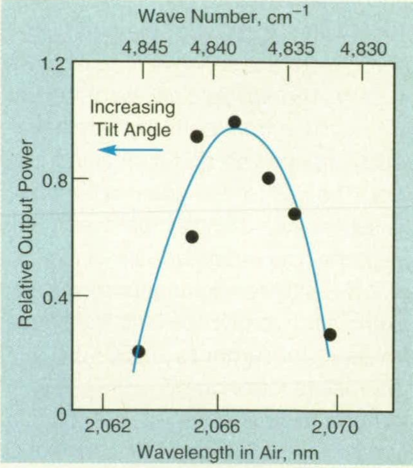


Figure 2. The **Tuning Range** of the laser is a wavelength band about 7 nm wide (~15 cm^{-1}).

This work was done by Brendan T. McGuckin and Robert T. Menzies of Caltech for **NASA's Jet Propulsion Laboratory** *For further information,* ***write in 107*** *on the Reader Information Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office–JPL through the Technology Transfer Office (see page 14). Refer to NPO-18611.

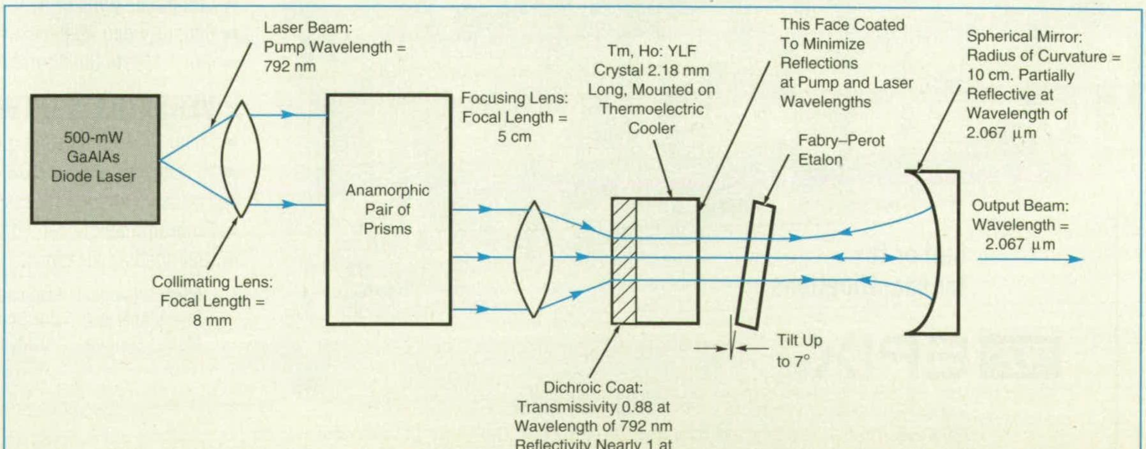


Figure 1. The **Continuous-Wave, Diode-Pumped Tm,Ho:YLF Laser** is tuned by tilting the Fabry–Perot etalon and/or adjusting the temperature of the Tm,Ho:YLF crystal.

Optical Measurement of Propfan Deflections

Displacements are extracted from voltage pulses.

Lewis Research Center, Cleveland, Ohio

An optoelectronic system measures deflections of a rotating propfan. By measuring and processing the times of shadowing of beams from low-power helium–neon lasers, the system provides data on the deflections of the leading and trailing edges of blade sections at three spanwise locations. The system is designed to accommodate the complicated shape and nonlinear deflections of rotating propfan blades.

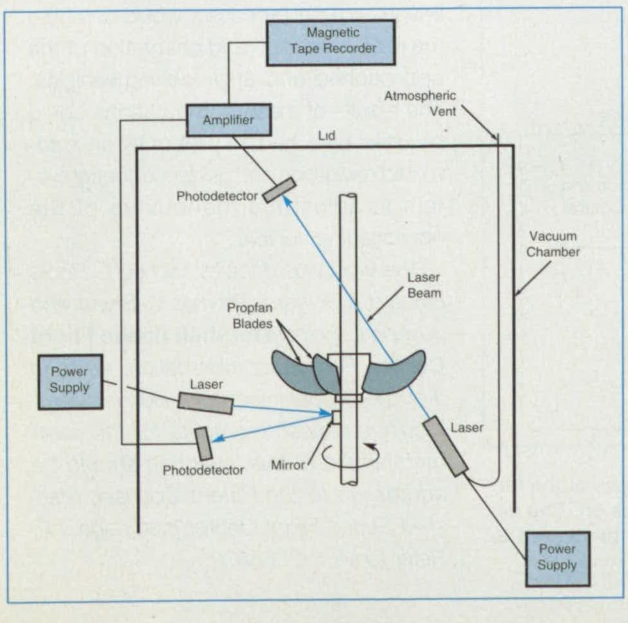
In addition to 0.5-mW HeNe lasers, the system includes Schottky-barrier photodetectors, neutral-density filters, signal amplifiers, an output-signal-recording device, and a digitizer. Each laser used to measure deflections is oriented so that its beam of light passes through the plane of rotation of the propfan blades (see figure), and when not obstructed by a blade, the beam impinges on a photodetector, producing a positive voltage signal on it. Three such laser/photodiode pairs are used—one for each of the measurement locations on the propeller span. The neutral-density filters are placed on the photodetectors to attenuate the laser beams to a safe level.

When the propfan blades interrupt the laser beams during rotation, the photodetectors produce negative voltage pulses. A narrow beam is essential to generation of the square-wave pulses that are required for proper analysis of deflections.

A fourth laser is positioned so that its beam is reflected from a mirror located on the propeller shaft to a photodetector. This laser/photodetector pair provides a once-per-revolution pulse as a reference for analysis.

The amplifiers process the four photodetector signals, which are then recorded on magnetic tape. The taped signals are digitized and fed to a computer for analysis. A specially developed computer code calculates the displacements of the blade sections at each of the three spanwise measurement stations.

The system has been adapted for use in a vacuum chamber for correlation of finite-element simulations of deflections. Measurements were done at a low pressure of 1 torr (about 0.13 kPa) to reduce aerodynamic effects to negligible levels and thus concentrate only on centrifugal effects. In this application, the low-pressure air around the laser electrodes ionized, short-circuiting them and extinguishing the lasers. The solution was to seal the glass plasma tube of each laser away from the low-pressure environment within its aluminum casing in a way that did not obstruct the laser beam. The



The **Laser Beam Passes** through the plane of rotation of the propfan blades. The beam is one of three that measure displacements at different blade sections. The additional laser beam at the bottom generates a shaft-rotation timing signal.

space between the glass plasma tube and the case — where the electrodes are located — is connected to the atmosphere through a plastic tube that runs through the lid of the vacuum chamber. Surrounded by air at atmospheric pressure, the electrodes no longer create ionization.

This work was done by John K. Ramsey, Erwin H. Meyn, Oral Mehmed, and Anatole P. Kurkov of **Lewis Research Center.** *For further information,* ***write in 64*** *on the Reader Information Request Card.*
LEW-15678

Synchronized Flashing Lights for Approach and Docking

Optical power could be reduced, with consequent enhancement of safety.

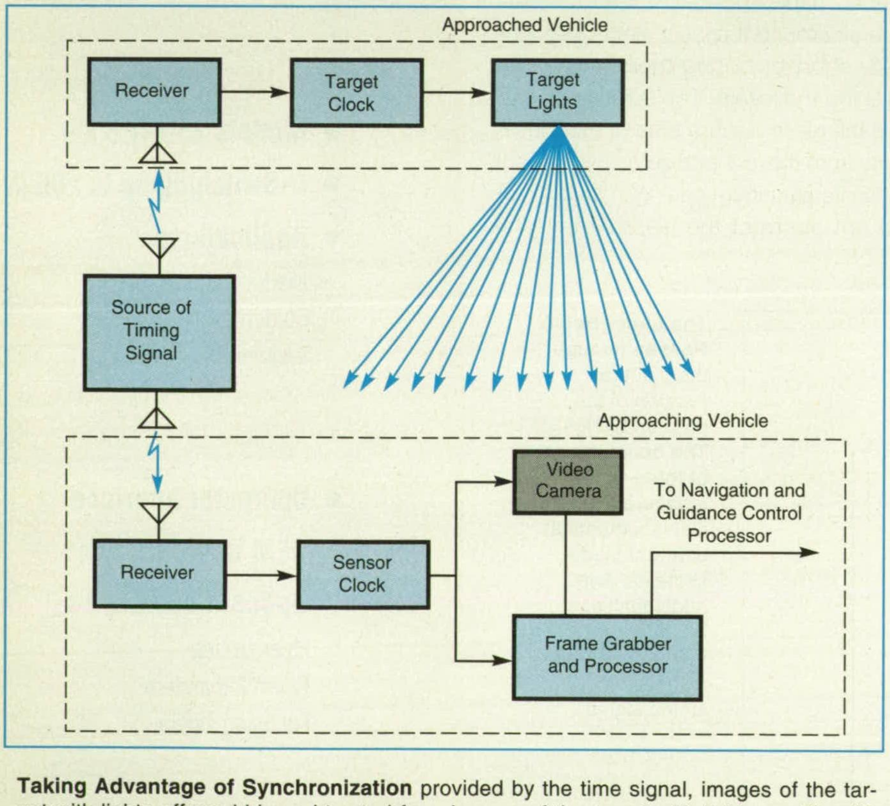
Marshall Space Flight Center, Alabama

A proposed optoelectronic system for guiding a vehicle in approaching and docking with another vehicle would include active optical targets (flashing lights) on the approached vehicle synchronized with sensor and image-processing circuitry on the approaching vehicle (see figure). The system was conceived for use in automated approach and docking of two spacecraft; in this use, synchronization would be provided by the time signal broadcast via the Global Positioning System (GPS). The underlying concept of the system should also be applicable on Earth to manually controlled and automated approach and docking of land vehicles, aircraft, boats, and submersible vehicles, using GPS or terrestrial broadcast time signals for synchronization.

The principal advantage of placing active optical targets on the approached vehicle, instead of using passive reflective targets on the approached vehicle illuminated from the approaching vehicle, is that less illuminating power is needed to make the target appear equally bright to the sensor(s) on the approaching vehicle. Decreasing the illuminating power enhances the eye safety of any personnel who may be present — an especially important consideration where the illumination is supplied by lasers. [In the proposed system, one does not have to use lasers: flashlamps or other incoherent sources could be used as long as they are bright enough to stimulate adequate responses from the sensor(s).]

The sensor aboard the approaching vehicle would be a video camera, the output of which would be acquired by a frame grabber and processed digitally. The time signal would be used to synchronize the frame grabber with the flashing lights in such a way that it would acquire video images in which the lights were on alternately with video images in which the lights were off. The "off" images would be subtracted from the "on" images to obtain difference images that contained mainly the lights themselves, with very little background or noise. Thus, the signal-to-noise ratio would be enhanced.

Then by use of (1) the known positions of the flashing lights relative to each other and to the rest of the approached vehicle and (2) the known geometric relationships between these positions and the apparent positions of the lights in the difference image, a digital processor would compute the relative position and orientation of the approached and approaching vehicles. The results of these computations could be used by a human pilot or by an automated navigation and guidance control system to adjust the maneuvers of the approaching vehicle.



Taking Advantage of Synchronization provided by the time signal, images of the target with lights off would be subtracted from images of the target with lights on. The difference image, which would have a high signal-to-noise ratio, would be processed to obtain data to guide the maneuvers of the approaching vehicle.

This work was done by Michael L. Book, Richard T. Howard, Thomas C. Bryan, and Joseph L. Bell of **Marshall Space Flight Center**. *For further information,* ***write in 1*** *on the Reader Information Request card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-28853.

Hydrogen-Maser/Ruby-Maser/Quartz-Crystal Oscillator

The performances of the component oscillators complement each other.

NASA's Jet Propulsion Laboratory, Pasadena, California

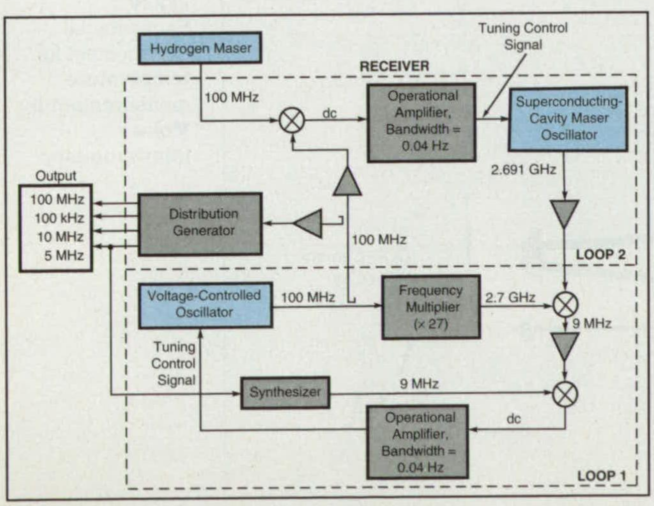
A highly stable oscillator suitable for use as a 100-MHz frequency standard consists of a 100-MHz hydrogen maser combined with a double-phase-locked-loop receiver (see figure). The receiver generates a 100-MHz signal with reduced noise. It contains a 100-MHz voltage-controlled quartz-crystal oscillator (VCO) locked in phase to a superconducting-cavity maser oscillator (SCMO). The SCMO, in turn, can be locked in phase to the hydrogen maser, thus effectively phase-locking the receiver and its SCMO/ VCO combination to the hydrogen maser.

Aspects of the SCMO have been described in previous reports, including "Performance of Superconducting-Cavity Maser" (NPO-18175), *NASA Tech Briefs*, Vol. 15, No. 6 (June 1991), page 30. This is an all-cryogenic, helium-cooled, three-cavity oscillator that consists of a ruby maser, a coupling cavity, and a superconducting lead-lined resonator cavity filled with sapphire. The ruby and resonator frequencies are matched by applying a bias magnetic field of about 500 gauss. The output power of this oscillator is $>10^{-9}$ W, which is more than 10^3 times that of the hydrogen maser; this relatively large output power makes it possible to obtain $\sqrt{1{,}000} \approx 30$ times the stability of the hydrogen maser at short (of the order of 1 s) measuring times.

An additional electromagnet coil installed on the ruby housing is used to vary the bias field to tune the SCMO to maintain phase lock with the hydrogen maser. The overall tuning range of the SCMO is only 1/1,000 that of the voltage-controlled quartz-crystal oscillator but is sufficient to accommodate the typical SCMO drift of 4×10^{-13} per day in long-term operation.

The double phase-locked loop is designed to combine optimally the inherent high medium-term frequency stability of the hydrogen maser with the inherent high short-term stability of the SCMO. As used here, "short-term" and "medium-term" denote measuring times (τ's) of the order of 1 and 10^3 s, respectively. Specific design goals are to preserve short-term stability of the SCMO through the phase-locked loop 1 and to optimize the phase-locked loop 2 so that the medium-term performance of the hydrogen maser is preserved without significantly degrading the performance at τ = 1 s. In a test, measured two-source fractional frequency stabilities of 2×10^{-14} and 1×10^{-15} were obtained at τ = 1 s and τ = 1,000 s, respectively. The 1-s value is approximately one tenth that of hydrogen masers, while the 1,000-s value is identical to that of the hydrogen maser.

This work was done by Rabi T. Wang and G. John Dick of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 61*** *on the Reader Information Request Card.*
NPO-18763



The Hydrogen-Maser/Receiver Combination can serve as frequency-standard oscillator that offers exceptional frequency stability over measuring times from as short as 1 s to more than 10^3 s.

PHYSICAL SCIENCES

Real-Time Noncontact Temperature Measurement for Manufacturing

A sensitive measurement technique based on Moire interferometry has less than 1°C resolution.

Center for High Technology Materials, University of New Mexico, Albuquerque, New Mexico

Temperature is a crucial variable for a large number of manufacturing processes, ranging, for example, from rapid thermal processing (RTP) of silicon wafers for implant annealing, oxidation and silicide formation to molecular beam epitaxial (MBE) growth of III-V semiconductors. Most process rates are governed by an Arrhenius temperature dependence (exponential in 1/T); precise and accurate measurement of temperature is vital to process control and manufacturability.

Noncontact techniques, which rely on optical signatures of the actual wafer temperature, are required in most applications. The most widely used noncontact temperature probe is pyrometry, but the emissivity variations associated with process-induced film growth and modification severely limit its precision. Several alternate temperature measurement schemes are under investigation, including a Moire interferometry technique that relies on diffraction from a grating embossed onto the wafer. As the wafer temperature increases, the grating expands, changing the diffraction angle.

The experimental arrangement is shown in Figure 1. Laser beams are symmetrically incident on the wafer's grating at an angle Θ_i. If the period, wavelength and incident angle are arranged so that the (-)first-order diffraction is close to normal to the surface, e.g., $\sin\theta_i - \lambda/d \sim 0$, then the angle between the two output beams, Φ, varies with temperature as:

$$\Delta\Phi = \Delta\Theta_l - \Delta\Theta_r$$

$$\Delta\Phi = \frac{2\alpha\lambda}{d}\Delta T$$

where α is the thermal expansion coefficient.

A vertically polarized HeNe laser beam (λ = 633µm) is split into two parts and the incident beams make angles ≈±39.25° with a 1.3-µm grating such that -1 orders diffracted from the grating are normal to the sample.

The use of the symmetrically incident beams provides a differential technique that, to first order, is independent of wafer tilt and warping during heating. The lens in the figure maps the angular variations in its focal plane. Thus the temperature measurement is reduced to a simple linear distance measurement that is readily performed with computer analysis of the CCD camera's output.

For an independent comparison with the optical technique, a thermocouple is cemented to the sample. A data acquisition system continuously monitors the diffraction-order separation. For the present system, the images are acquired at TV frame rates (1/30 second). Signal processing takes about 2 seconds for near-real-time measurements consistent with MBE requirements. Additional hardware and software development can easily achieve faster signal processing.

A temperature resolution of less than 1°C has been demonstrated over the entire range of interest for silicon processing (-150-1200°C). The technique shows good agreement with published results for silicon and gallium arsenide expansion coefficients. It is simple, inexpensive and adaptable to real-time process control.

This work was done by Prof. S. R. J. Brueck, Dr. S. H. Zaidi, Mike Lang and C. Huang of the **Center for High Technology Materials (CHTM),** *University of New Mexico, Albuquerque, New Mexico, with support from SEMATECH and DOD ARPA. CHTM is an R&D participant in the Alliance for Photonic Technology, Albuquerque, New Mexico.*

Inquiries concerning detailed information and rights for the commercial use of this invention should be addressed to Prof. S. R. J. Brueck, CHTM, University of New Mexico, Albuquerque, NM 87131, or alternatively to the Alliance for Photonic Technology, 851 University Blvd. SE, Bldg. 1, Suite 200, Albuquerque, NM 87106-4339; (505) 272-7001.

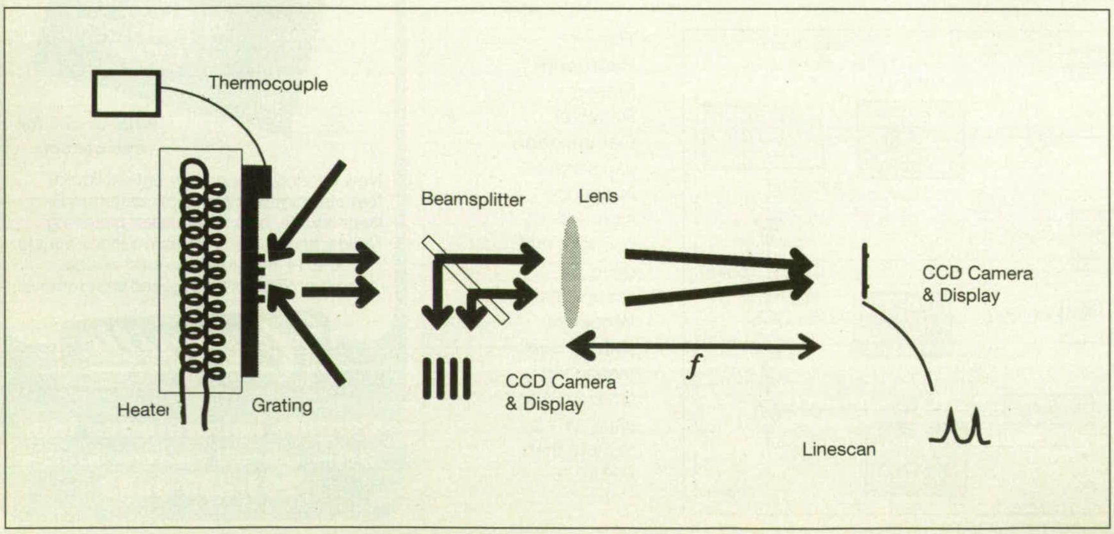


Figure 1. Experimental arrangement for **temperature measurement by Moire interferometry.**

Optical Fibers Would Sense Local Strains

Phase shifts in single-mode fibers would vary with strains.

Langley Research Center, Hampton, Virginia

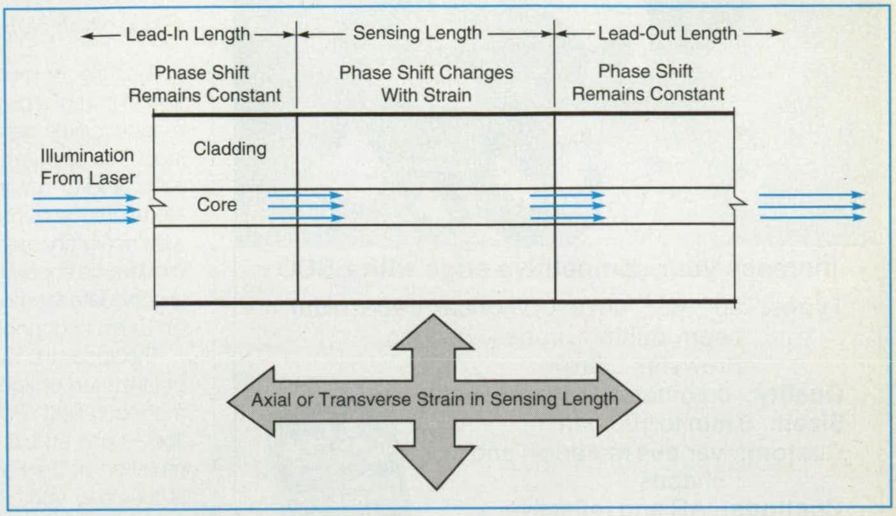
Fiber-optic transducers that would measure local strains have been proposed. The concept of these transducers was derived from research on the waveguide electromagnetic modes of few-mode optical fibers. This research showed, among other things, that a single-mode optical fiber can be made sensitive or insensitive to strain or to a particular kind of strain (e.g., axial or transverse strain) by appropriate choice of the design parameters of the fiber; these parameters include the indices of refraction of the core and cladding, the radius of the core, the photoelastic constants, and the Poisson's ratio. The wavelength of light must also be chosen in conjunction with these parameters because it affects the mode structure.

A typical fiber-optic sensor of this type (see figure) would include a lead-in length, a short sensing length, and a lead-out length. A laser at the lead-in end would excite the single-mode waveguide. The design parameters of the lead-in and lead-out lengths would be chosen so that the phase shifts of the single mode in them would be insensitive to strain. The design parameters of the sensing length would be chosen to make the phase shift of the single mode in that length sensitive or insensitive to a specific kind of strain (e.g., axial or transverse strain or some combination of these two). The phase shift would be measured and used to infer the strain in the short sensing length, which would be attached to an object at a location subject to strain.

In an alternative version, multiple portions of an optical fiber could be designed to be sensitive to strains characteristic of a specific vibrational mode of an object. In contrast, prior fiber-optic strain sensors have been sensitive along their entire lengths and thus have yielded data on integrated or average strains rather than on strains at specific locations. Furthermore, prior fiber-optic strain sensors have not distinguished between axial and other strains.

The same principle can also be used with a two-mode fiber. In this case, the sensitivity is equal to the difference of the phase shifts of the first and second mode: $\Delta\rho_{01}-\Delta\rho_{11}$. By making this difference equal to zero the fibers could be made insensitive to strain.

This work was done by Claudio O. Egalon of Analytical Services and Materials, Inc., and Robert S. Rogowski of **Langley Research Center**. *For further information,* ***write in 43*** *on the Reader Information Request Card.*



This **Fiber-Optic Transducer** would include lead-in and lead-out lengths that would produce no changes in phase shifts, plus a short sensing length in which the phase shift would be sensitive to strain.

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be made to the Patent Counsel, Langley Research Center [see page 14]. Refer to LAR-14810.

Fiber-Optic Ammeter

Magnetic field generated by electric current would be measured via the Faraday effect.

Goddard Space Flight Center, Greenbelt, Maryland

A single- or multiple-turn loop of low-loss, single-mode optical fiber is part of a proposed apparatus that would be sensitive to the magnetic field generated by electric current flowing through the loop. The apparatus is being developed to measure electric currents and/or magnetic fields in outer space as part of an effort to determine number densities and directions of movement of electrically charged particles; a loop of low-loss optical fiber can be made large enough that the number of charged particles encircled is adequate for measurement. The apparatus could also be used on Earth in noncontact measurements of electric currents.

The apparatus would exploit the Faraday effect — the rotation of polarization of light as the light passes through matter along a magnetic field. Polarized light would be launched into the optical fiber at one end, and the change of polarization caused by accumulation of the Faraday effect along the fiber would be measured at the other end. The magnetic field along the loop (and, equivalently, the electric current through the loop) could then be computed from the change in polarization. In comparison with a flux magnetometer, this apparatus could, in principle, be more sensitive to magnetic fields. Another important advantage of this apparatus is that it would not produce a magnetic field, so that its effect on the measured magnetic field or current should be minimal.

In addition to the fiber-optic loop, the apparatus would include a stable source of coherent light and a high-resolution optical receiver that could measure the change of polarization in terms of a change of phase between orthogonal polarizations.

A prototype of the apparatus was built to demonstrate feasibility. It included a laser diode as the source of coherent light, a fiber-optic loop of 75 turns and a diameter of about 1m, and a homodyne receiver that had phase resolution 1 to 2 orders of magnitude better than previously reported in the literature. One important feature of the prototype was unique optics that produced three phase values 120° apart simultaneously. Another important feature was a novel algorithm, implemented in hardware, that generated high-resolution phase measurements independent of the intensities of signals. Tests of this apparatus revealed some undesired effects that involved stress-induced birefringence in the fiber and instabilities of the laser diode caused by optical feedback. Apart from these effects, it appears that the proposed measurement technique would be practical, at least in the original intended outer-space application.

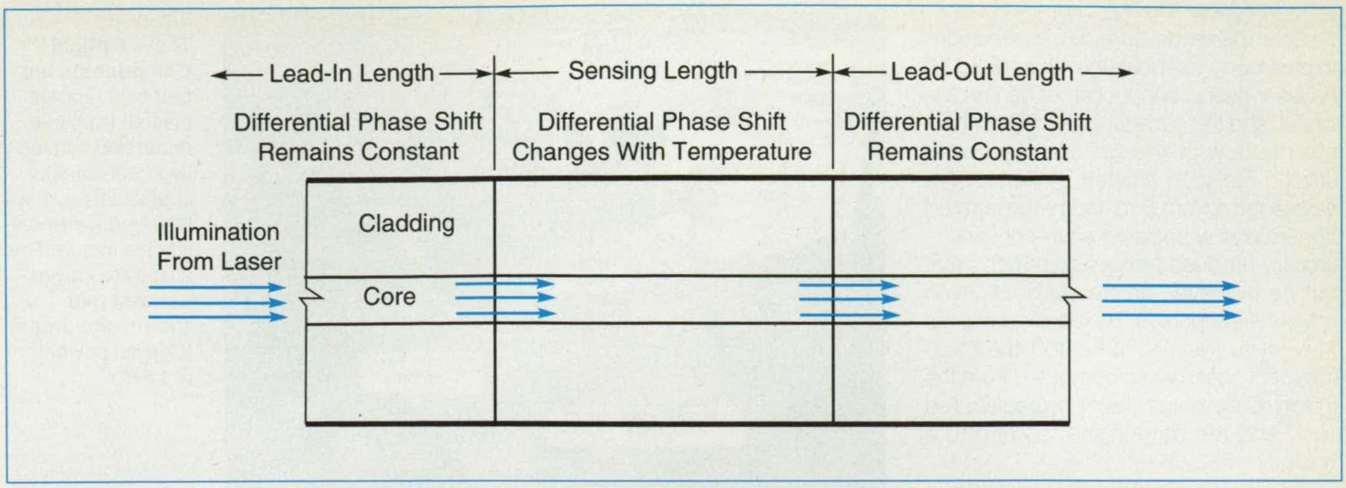
This work was done by Geert Wyntjes of OPTRA, Inc., for **Goddard Space Flight Center**. *No further documentation is available. GSC-13288*

Optical Fibers Would Sense Local Temperatures

Phase shifts in two-mode fibers would vary with temperatures.

Langley Research Center, Hampton, Virginia

Fiber-optic transducers that would measure local temperatures have been proposed. The concept of these transducers was derived from research on the waveguide electromagnetic modes of few-mode optical fibers. This research showed, among



This **Fiber-Optic Transducer** would include lead-in and lead-out lengths that would produce no changes in phase shifts, plus a short sensing length in which the phase shift would be sensitive to temperature.

other things, that the difference between the phase shifts in two waveguide modes along a given length of a two-mode optical fiber can be made sensitive or insensitive to temperature by appropriate choice of the design parameters of the fiber; these include the indices of refraction of the core and cladding, the radius of the core, the coefficient of thermal expansion, and the analogous coefficients of the changes in the indices of refraction with changes in temperature. The wavelength of light must also be chosen in conjunction with these parameters because it affects the mode structure.

A typical fiber-optic sensor of this type (see figure) would include a lead-in length, a short sensing length, and a lead-out length. A laser at the lead-in end would excite the two waveguide modes. The design parameters of the lead-in and lead-out lengths would be chosen so that the differences between the modal phase shifts in them would be insensitive to changes in temperature. The design parameters of the short sensing length would be chosen to maximize the sensitivity of this differential phase shift to changes in temperature. The change in the differential phase shift would be measured and used to infer the change in the temperature at the sensing location.

This work was done by Claudio O. Egalon of Analytical Services and Materials, Inc., and Robert S. Rogowski of **Langley Research Center**. *For further information,* ***write in 37*** *on the Reader Information Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 14]. Refer to LAR-14891.

Laser Measurement of Convective-Heat-Transfer Coefficient

The measurement spot can be scanned across the surface of the model.

Lewis Research Center, Cleveland, Ohio

The coefficient of the convective transfer of heat at a spot on the surface of a wind-tunnel model can be computed from measurements acquired by a developmental laser-induced-heat-flux technique. When fully developed, this technique will enable non-intrusive measurements of convective-heat-transfer coefficients at many points across the surfaces of models in complicated, three-dimensional, high-speed flows. Whereas such measurements in older techniques were restricted to the fixed locations of flush-mounted heat-flux gauges, the measurement spots in this laser-induced-heat-flux technique can be scanned across the surfaces to obtain comprehensive data.

The prototype measurement apparatus includes an argon-ion laser, an attenuator/beam splitter that controls the amount of laser power applied to the model, an electronic shutter that controls the duration of the applied power, an infrared camera, and a subsystem that measures the power of the laser beam (see Figure 1). The apparatus is mounted on a three-axis positioning table, which is used to scan across the model. Optical access to the interior of the wind tunnel is provided by a zinc sulfide window, which transmits light at the visible and infrared wavelengths of interest.

The laser beam (green light of a wavelength of 514.5nm) impinges on the measurement spot on the model. The resulting distribution of temperature in and around

the spot depends upon known relationships among the heating of the model by the laser beam, conduction of heat in the model, and the convective transfer of heat into the flow at the surface. By use of infrared radiation emitted by the spot at wavelengths from 8 to 14μm, the infrared camera and associated scan-conversion circuitry produce temperature maps that can be displayed as standard television images (see Figure 2). The coefficient of the convective transfer of heat at the measurement spot can be computed from the known relationships, the measured applied heat, and the data in the temperature maps.

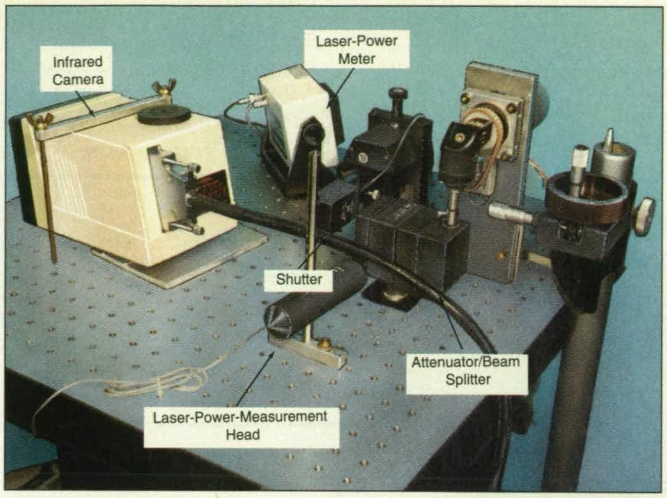


Figure 1. These **Optical Components** are part of an apparatus that is used to determine convective-heat-transfer coefficients by the laser-induced-heat-flux technique. The associated argon-ion laser (not shown) operates at a typical power of 1.5W.

The prototype apparatus was tested in an experiment on the supersonic flow of air over a flat plate in a wind tunnel at nominal mach numbers of 2.5, 3.0, 3.5, and 4.0. The plate was also instrumented with a thermocouple and pressure taps. The flows in the boundary layers underwent transitions from laminar to turbulent.

Convective-heat-transfer coefficients were computed from the measurements in this experiment and compared with theoretical convective-heat-transfer coefficients of boundary layers in high-speed laminar flows. The two sets of coefficients were found to be in reasonable agreement, but some scatter in the experimental data was observed. Some of the scatter was attributed to minor problems in the data-acquisition process. Also, because of a deficiency in the temperature calibration of the infrared camera, the variation in a factor used to recover the temperature that the surface would attain under adiabatic conditions could not be determined, and the resulting convective-heat-transfer coefficients that were computed for the transitional portions of the boundary layers were not accurate.

This work was done by A. Robert Porro, Warren R. Hingst, Randall M. Chriss, and Kirk D. Seablom of **Lewis Research Center** *and Theo G. Keith, Jr., of the University of Toledo. Further information may be found in NASA TM-103778 [N91-19063], "Development of a Laser-Induced Heat Flux Technique for Measurement of Convective Heat Transfer Coefficients in a Supersonic Flowfield."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-15494

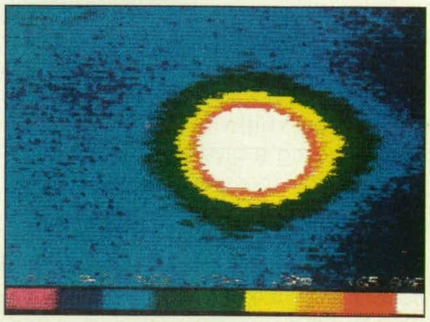


Figure 2. This **Infrared Thermogram** shows the distribution of temperature on the surface of a flat plate heated by a laser.

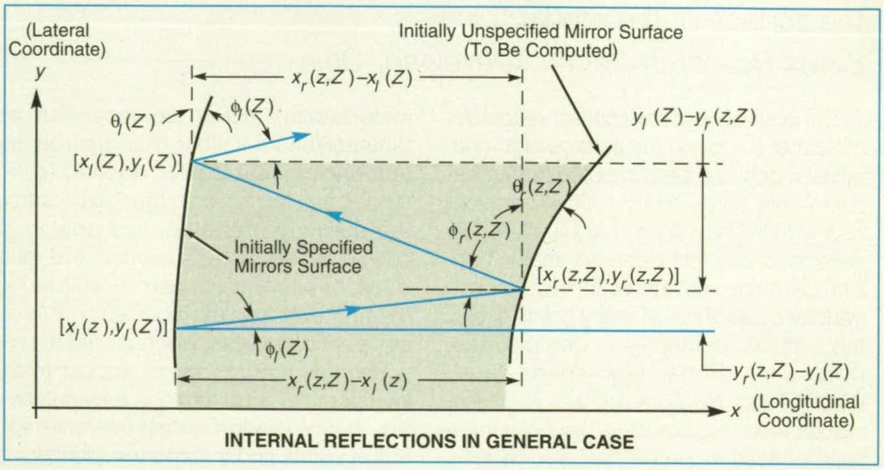
Designing Aberration-Corrected Solid Unstable Resonators

Shapes of mirrors can be calculated to yield specified mode.

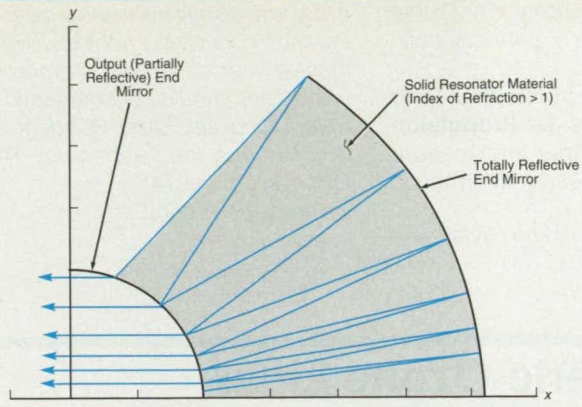
NASA's Jet Propulsion Laboratory, Pasadena, California

In an improved method of designing the solid unstable resonator of a laser diode, one specifies a priori the output electromagnetic mode and the shape of one of the two end mirrors of the resonator, then computes the shape of the other end mirror consistent with the chosen mode. This can be regarded partly as a reversal of the previous design procedure, in which one first specified the design of the resonator, then computed the mode that it produced.

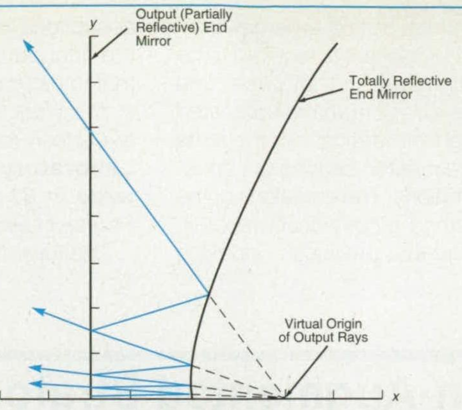
Heretofore, only mirrors of circular cross section have been used, and they have often been designed under paraxial-ray assumptions. Such mirrors produce optical aberrations, which can be large when apertures are large. In the improved method, one proceeds directly to computation of the design for the desired mode. There is no need to accept aberrations or suboptimal circular shapes, to make iterative design computations in the effort to



Ray Tracing is used to compute the shape of the initially unspecified end mirror, given the shape of the initially specified end mirror and the specified output mode.



EXAMPLE: A SELF-COLLIMATING RESONATOR



EXAMPLE: MIRRORS THAT PRODUCE SPHERICAL-WAVE OUTPUT THROUGH A FLAT OUTPUT MIRROR

converge on the desired mode, or to assume paraxiality of rays: Angles between rays and the optical axis can be large, cross sections of surfaces can be noncircular, and the computed shape of the end mirror is exact. Thus, the end mirror corrects for all aberrations.

The improved method is based on the well-known principles of ray tracing: Rays of light are traced within the resonator between points of reflection on the end mirrors and as they are refracted through one of the end mirrors (the partially reflective output mirror) into the exterior space (see figure). The desired output mode (e.g., collimated beam or rays emanating from a single virtual point) is made to affect the design of the resonator by tracing the output rays back through the output mirror into the resonator and imposing the applicable conditions on reflections at the two end mirrors.

The initially specified end mirror could be either the output mirror or the other one, and the longitudinal x and lateral y coordinates of its surface are expressed parametrically in the form $[x(z),y(z)]$, where z is an arbitrary parameter. This specification is combined with the applicable ray-tracing equations in such a way as to obtain a first-order, nonlinear differential equation for an integrated magnification Z, which is a function of z and which appears in other parametric equations that satisfy the ray-tracing equations. The differential equation is integrated numerically, and the resulting integrated magnification $Z(z)$ is inserted in the parametric equations, from which the shape of the initially unspecified mirror surface is then computed. The resulting computed mirror surface can be fabricated by use of lithographic techniques.

The improved method is not limited to the simple configurations shown in the figure. For example, the optical train through which the light beam from the laser diode passes could include collimating lenses and possibly other optical components that introduce aberrations. Suppose that

the final output beam that emerges from the last such component is required to be perfectly collimated. In that case, one could trace rays back from the collimated output through the optical components and into the resonator, bearing the accumulated aberrations. The equations of the improved method automatically result in a mirror design that produces opposing aberrations within the resonator, such that the final output beam is perfectly collimated as required.

This work was done by Robert J. Lang of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 81*** *on the Reader Information Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Laser Resident Office–JPL through the Technology Transfer Office [see page 14].
Refer to NPO-18662.

Raman-Augmented Stratospheric-Ozone Lidar

Raman scattering from nitrogen provides data to correct for effects of aerosols.

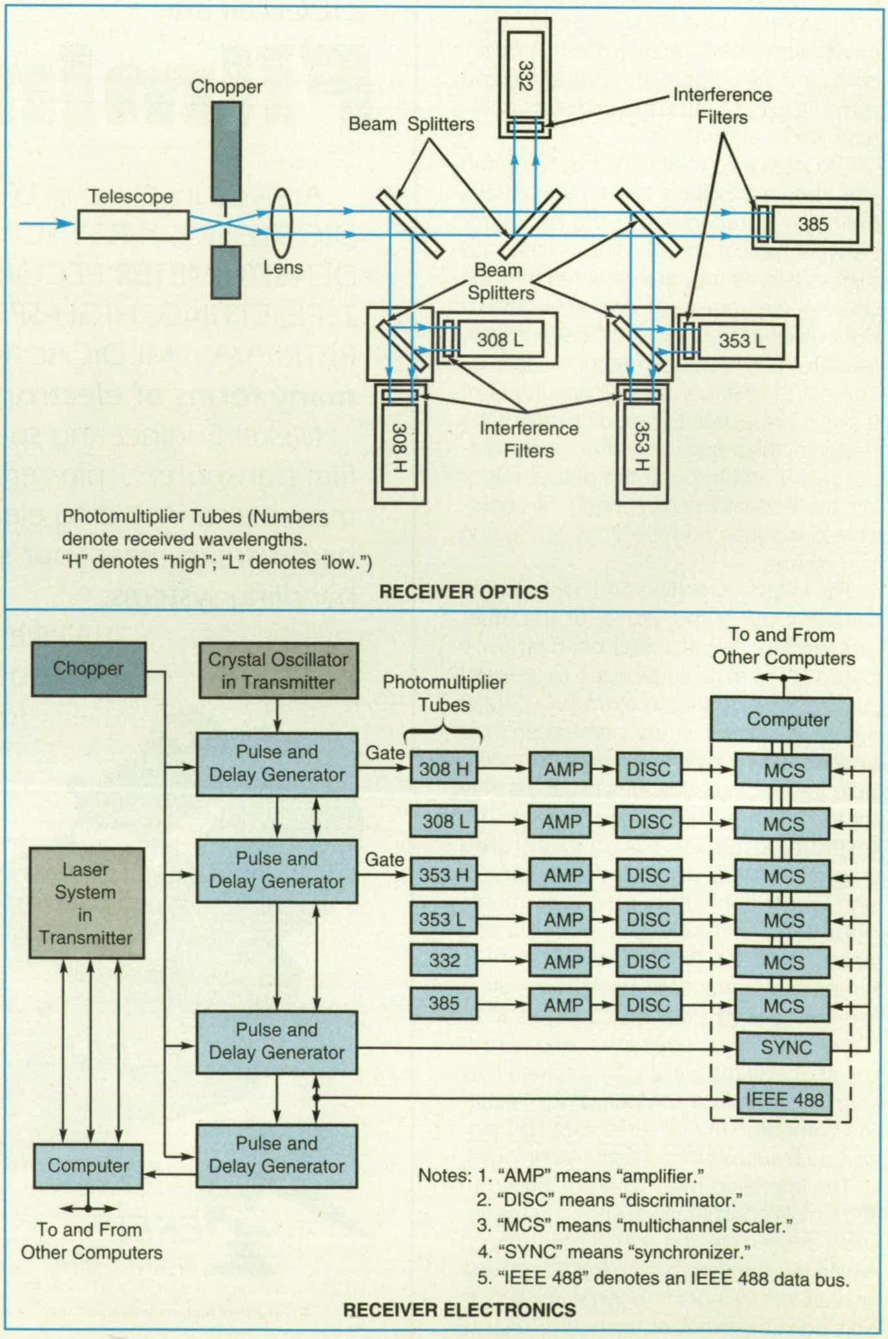
NASA's Jet Propulsion Laboratory, Pasadena, California

A differential-absorption lidar (DIAL) system that measures the concentration of ozone in the stratosphere has been augmented with a subsystem that measures Raman scattering from nitrogen. The particular DIAL system, located at Mauna Loa, Hawaii, is part of the international Network for the Detection of Stratospheric Change: as such, it is one of a number of DIAL systems to be used in long-term monitoring of stratospheric ozone.

The volcanic eruption of Mount Pinatubo generated stratospheric aerosols, which have affected DIAL measurements since 1991, preventing accurate determinations of concentrations of ozone as functions of altitude. The Raman-augmentation technique used in this DIAL system provides return signals from Raman backscattering by nitrogen molecules only (not by aerosols): these signals can be used to compute a correction for differential backscattering by aerosols. (A further small correction for differential extinction by aerosols might still be needed but is beyond the scope of the development reported here.)

The transmitter in this Raman-augmented DIAL system is a 100-W, low-divergence xenon chloride excimer laser, which operates at 308nm wavelength for backscattering by ozone. The reference wavelength of 353nm is generated in the transmitter by Raman scattering of part of the laser-beam power in hydrogen. The receiver includes a 1-m-wide telescope.

The Raman augmentation of the system includes the addition of two wavelength channels to the optical and electronic assemblies in the receiver (see figure). The quality of the receiving optics has been improved over that of a previous DIAL system. The data-acquisition electronics include new personal-computer-based



Channels at Wavelengths of 332 and 385 nm are added to the DIAL receiver to measure Raman backscattering from nitrogen molecules in the stratosphere. The data-acquisition electronics can sample photon counts at a rate of 250 MHz.

photon-counting multichannel-scaler circuitry with synchronization among all of the counting/wavelength channels. This circuitry enables counting at a rate of 250 MHz — much faster than in the previous DIAL system.

This work was done by I. Stuart McDermid of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 63*** *on the Reader Information Request Card. NPO-18869*

Solar Rotating Fourier Telescope

The full Sun could be imaged at unprecedented resolution.

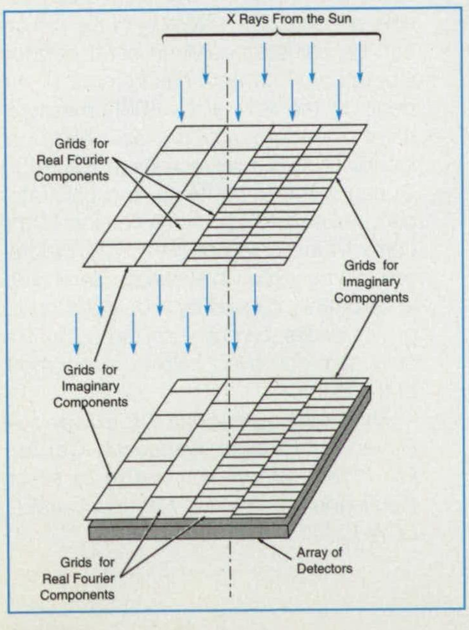
Marshall Space Flight Center, Alabama

A proposed telescope based on absorbing Fourier-transform grids would image the full Sun in hard x rays (10- to 100-keV photons) at an angular resolution of 1 to 5 arc seconds and temporal resolution (photodetector integration time) of about 1 second. Conventional optical components like lenses and mirrors cannot refract and/or reflect hard x rays sufficiently to produce useful images. Pinhole masks can produce x-ray images, but the resolution is typically much coarser than desired. The proposed Fourier telescope would overcome the limitations of both conventional optical and pinhole cameras.

The Fourier-transform grids would be made of tungsten or other high-atomic-number material 3 mm thick. The telescope structure would be a truss 5 m long. The grids would be mounted at the ends of the truss in trays of graphite/epoxy or similar material that has a low coefficient of thermal expansion. An aluminum shield 1 mm thick on the outer end of the telescope (facing the Sun) would block soft-x-ray and lower-energy photons.

There would be a total of eight grids with two trays holding four each; the slits and slats in two of the grids in a tray would be of one width (e.g., 0.0125 cm), while the slits and slats in the other two grids would be of a different width (e.g., 0.0275 cm). The slit widths of 0.0125 and 0.0275 cm would provide an angular resolution of about 4 arc seconds; other widths could be chosen to obtain better angular resolution.

Grids of the same slit and slat width in the two trays would be aligned in pairs: the two grids of one pair would



Arrays of Grids and Detectors would be configured for sensitivity to selected Fourier components of x-ray images.

be positioned so that when viewed along the optical axis of the telescope, their slits would coincide with each other; the two grids of the other pair would be positioned so that when viewed along the optical axis, their slits would be offset laterally by half the slit width. The figure illustrates schematically the alignment of the grids with respect to each other and to the optical axis. The coincident-slit pairs would pass real Fourier components; the offset-slit pairs would pass imaginary Fourier components.

A coarse linear imaging detector containing eight NaI scintillators would be mounted under each grid at the end of the telescope that faces away from the Sun. The total grid and detector area would be a square of 10 by 10cm. The detectors would convert x-ray photons to electronic signals (as functions of photon energy). These signals would be processed by standard methods to obtain the real and imaginary Fourier components of the image along one axis. The telescope would then be rotated 180° about the optical axis to measure the Fourier components of the image across the entire Fourier plane. The Fourier components would then be inverse Fourier-transformed and deconvolved to obtain the x-ray image of the Sun.

The performance of the telescope has been analyzed by computer simulation, using distributions of hard-x-ray brightness from theoretical models of solar flares. The results of the simulations showed that the telescope should be capable of imaging solar flares of at least moderate brightness, and that the images would be distinctive enough to provide insight into turbulent magnetic-field and plasma processes on the Sun.

This work was done by Jonathan Campbell of **Marshall Space Flight Center**. *For further information,* ***write in 68*** *on the Reader Information Request Card. Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-28795.*

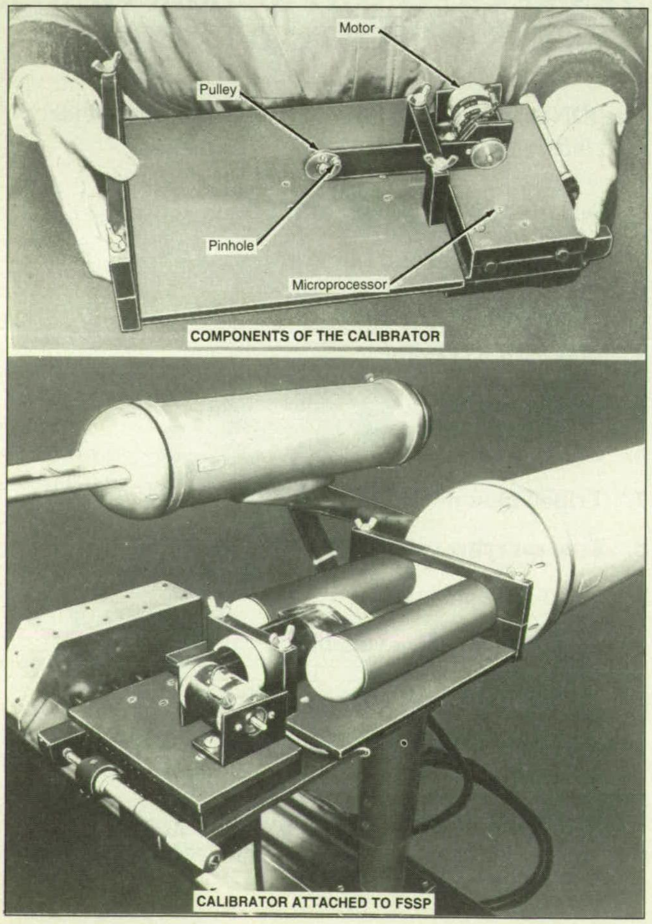
Revolving-Pinhole Calibrator

The pinhole serves as a diffraction standard for measuring small particles and drops.

Lewis Research Center, Cleveland, Ohio

The upper part of the figure shows a revolving-pinhole calibrator, which is used to calibrate an instrument called the "Forward Scattering Spectrometer Probe" (FSSP). This instrument measures light scattered from water droplets in icing clouds. The scattering patterns are used to determine the sizes and the distribution of sizes of the droplets in connection with safety-oriented studies of icing on aircraft.

The calibrator includes a pulley that contains a precise pinhole near its edge. The pulley is rotated by a motor via another pulley and a drive belt. These mechanisms are mounted on a two-axis positioning table to enable adjustment of the trajectory of the pinhole.



The **Revolving-Pinhole Calibrator** is attached to the FSSP to provide a precisely moving diffraction pattern.

The calibrator is attached to the FSSP as shown in the lower part of the figure, and the trajectory is adjusted so that the pinhole passes repeatedly through a laser beam of the FSSP. The pinhole diffracts the laser light into a known scattering pattern, which should cause the FSSP to respond in a predicted way. If the FSSP responds otherwise than as predicted, then it is deemed to be out of calibration.

The revolving-pinhole calibrator machine offers several advantages for calibration. The diameter of the pinhole and, therefore, its diffraction pattern are known precisely. The pinhole is a stable, durable, reusable standard. The trajectory of the pinhole can be adjusted easily in such detailed laboratory work as measurement of the depth of the field of the FSSP, measurement of the profile of the laser beam, or identification of malfunctions in the FSSP. During wind-tunnel tests, the calibrator can be used for quick verification of the correct functioning of the FSSP (calibration can be verified in seconds). Small shifts in calibration, caused by misaligned optics or wet lenses, can be detected easily. The calibrator can even help in realignment of the FSSP.

This work was done by Edward A. Hovenac of **Lewis Research Center**. *For further information,* ***write in 97*** *on the Reader Information Request Card.*
LEW-15450

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Solar Photovoltaic Array With Mini-Dome Fresnel Lenses

The lenses concentrate sunlight onto small solar cells.

Lewis Research Center, Cleveland, Ohio

Solar photovoltaic arrays are being developed according to an improved design that features dome-shaped Fresnel lenses that concentrate sunlight onto the photovoltaic cells. These arrays offer significant increases in real performance over current flat-plate, one-sun solar photovoltaic arrays. A prototype array that contains high-efficiency gallium arsenide cells has been fabricated. This technology corresponds to a specific power density of 250 W/m^2 and a specific power output of 80 W/kg. Through the use of new multijunction photovoltaic devices, the efficiency of the cells could be increased to 30 percent; the corresponding performance figures would be 300 W/m^2 and 100 W/kg. These values are approximately double those of one-sun arrays using silicon cells.

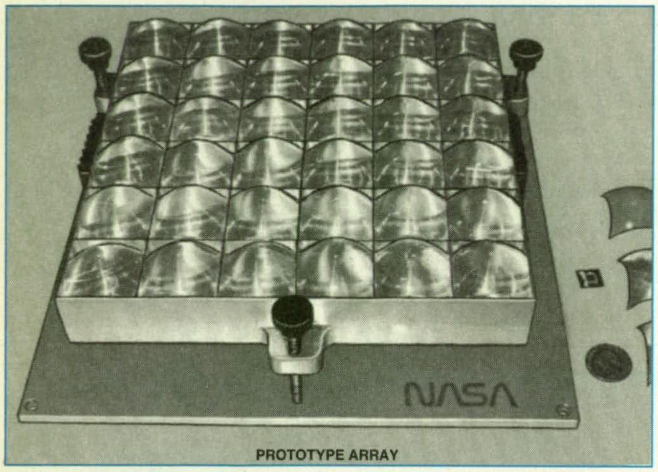
Each element of an array includes one photovoltaic cell and one dome-shaped Fresnel lens, the conical facets of which are designed to minimize reflective losses (see figure p.54). An optical transmission efficiency of 90 percent has been achieved; further design refinements could increase the efficiency beyond 95 percent.

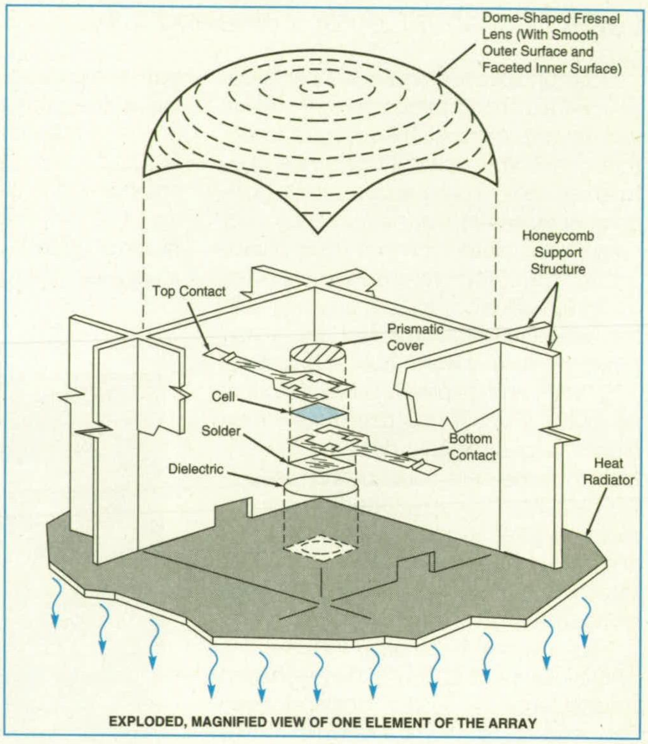
The slopes of the conical facets of the domed concentrator are chosen so that each facet, acting in conjunction with the opposite smooth dome surface, refracts light at the angle of minimum deviation; i.e., light enters the concentrator through the dome surface and leaves the concentrator through the facet at the same angles of refraction with respect to both surfaces. At any other combination of angles, reflective losses would be higher. In comparison with photovoltaic arrays equipped with reflective or conventional flat Fresnel lens concentrators, the mini-dome concentrator arrays are more than 200 times as tolerant of slope errors; this feature reduces sensitivity to thermal expansion.

The Fresnel-lens concentrator focuses light onto the photovoltaic cell at a sunlight concentration ratio of 50 to 100, depending upon the cell size chosen. A thin prismatic cover on the cell redirects the incident light away from the metal contacts on the surface of the cell toward the bulk of the semiconductor, where it is absorbed. This eliminates reflective losses from the contacts, which typically range from 10 to 20 percent on an otherwise bare cell.

The mass of a domed-concentrator array with 30-percent-efficient cells could be as little as half that of one-sun systems with comparable power output. In addition to the gains in performance, the cost of these refractive concentrator arrays should be significantly lower. In a concentrator array, the amount of expensive photovoltaic cell material is reduced by a factor of 50 to 100 and replaced by a relatively low cost concentrator lens. The simple design of the mini-dome concentrator array is also easily adaptable to the automated manufacturing techniques currently used by the semiconductor industry. These performance and cost advantages make the mini-dome Fresnel lens concentrator an attractive option for a variety of future space missions.

This work was done by Michael F. Piszczor, Jr., of **Lewis Research Center** *and Mark J. O'Neill of Entech, Inc. For further information,* ***write in 27*** *on the Reader Information Request Card.* LEW-15520





Mini-Dome Fresnel Lenses concentrate sunlight onto individual photovoltaic cells. The facets of the Fresnel lens are designed to refract incident light at the angle of minimum deviation to minimize reflective losses. A prismatic cover on the surface of each cell reduces losses by redirecting incident light away from the metal contacts toward the bulk of the semiconductor, where it is usefully absorbed.

Determining Directional Emittance With an Infrared Imager

The advantages are simplification of measurement procedure and reduction of cost.

Langley Research Center, Hampton, Virginia

The directional emittances of a flat specimen of a smooth-surfaced, electrically nonconductive material at various temperatures can be computed from measurements taken by an infrared radiometric imager operating in conjunction with some relatively simple ancillary equipment. Of course, the directional emittances thus obtained are integrated, with the spectral-response weighting of the imager, over the spectral passband of the imager. These directional emittances are useful in extracting detailed variations of surface temperatures from infrared images of curved, complexly shaped other specimens of the same material. In comparison with more-elaborate goniometric spectrophotometric techniques, this technique for determining directional emittances involves simpler measurement procedures and costs less.

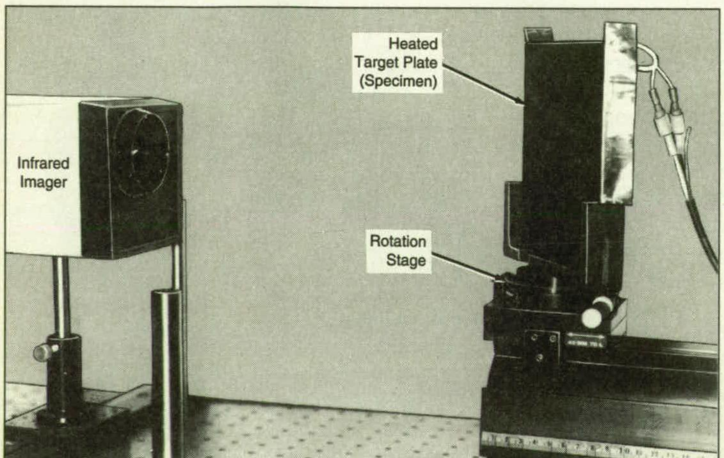


Figure 1. The **Infrared Imager** measures the apparent temperature of a target plate heated to a known temperature and oriented at known angles.

Figure 1 illustrates a prototype apparatus used to demonstrate the technique. An infrared imager was aimed horizontally toward a copper target plate, which was mounted on a rotation stage for precise angular positioning about a vertical axis. An electrical heating pad was attached to the back side of the target plate. The front side of the target plate was coated with the specimen material, which was a flat black lacquer in one set of measurements and a red epoxy in another set of measurements.

Once each target came to thermal equilibrium at each designated temperature, the rotation stage was used to orient the surface at various angles with respect to the optical axis of the infrared imager. At each angle, the image-processing hardware and software of the imager were used to compute the apparent absolute temperature of a small region of the target plate centered at the intersection of the optical and rotation axes. The value of the emittance used in the software to convert the raw measurement data into apparent temperatures was

the spectral normal emittance (the spectral emittance along a line of sight perpendicular to the surface) integrated, with the spectral-response weighting of the imager, over the 8- to 12-μm-wavelength passband of the imager.

In general, the apparent temperature of the target (T_a) obtained by such a procedure differs from the actual temperature (T) of the target by an amount that depends on the known relationship among these temperatures, the ambient temperature (T_∞), the relative spectral response [$R(\lambda)$] of the imager, absolute directional emittance [$\varepsilon(\theta)$ at angle θ] and the absolute normal emittance (ε_n) (see Figure 2). This relationship yields the following equation for the ratio between the directional and normal emittances:

$$\frac{\varepsilon(\theta)}{\varepsilon_n} = \int_{\lambda_1}^{\lambda_2} R(\lambda)\lambda^{-5}(1/(\exp(C_2/\lambda T_a)-1) - 1/(\exp(C_2/\lambda T_\infty)-1))d\lambda \Big/ \int_{\lambda_1}^{\lambda_2} R(\lambda)\lambda^{-5}(1/(\exp(C_2/\lambda T)-1) - 1/(\exp(C_2/\lambda T_\infty)-1))d\lambda$$

where λ denotes wavelength, λ_1 and λ_2 denote the wavelength limits of the passband of the imager, and C_2 is the constant that appears in the exponential term in Planck's radiation law. Then if ε_n is also known, $\varepsilon_o(\theta)$ can be calculated by multiplying the result of this equation by ε_n.

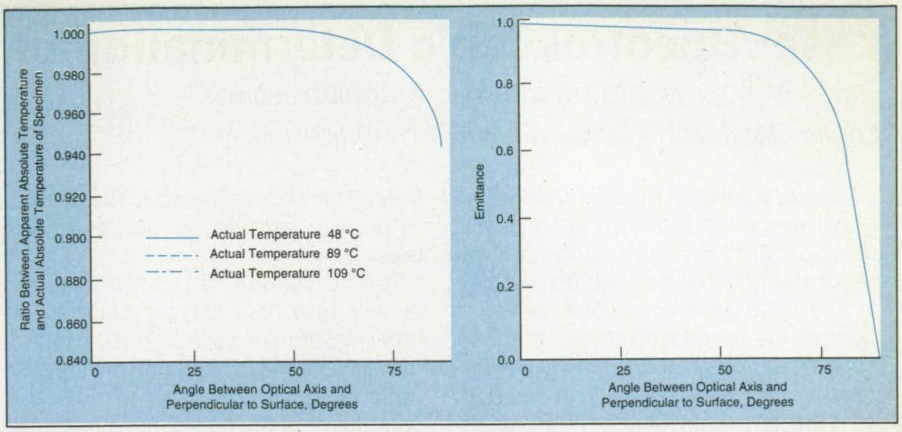


Figure 2. The **Directional Emittance** of a target plate coated with flat black lacquer was computed from the known relationship among various quantities that include the apparent and actual temperatures at various angles.

This work was done by Kamran Daryabeigi, David W. Alderfer, and Robert E. Wright, Jr., of **Langley Research Center** *and Chith K. Puram of Vigyan, Inc. No further documentation is available.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Chith K. Puram
Vigyan, Inc.
30 Research Dr.
Hampton, VA 23666

Refer to LAR-14971, volume and number of this Laser Tech Briefs *issue, and the page number.*

Laser/Spectroscopic Determination of Mass Flows

Rates of flow would be measured nonintrusively.

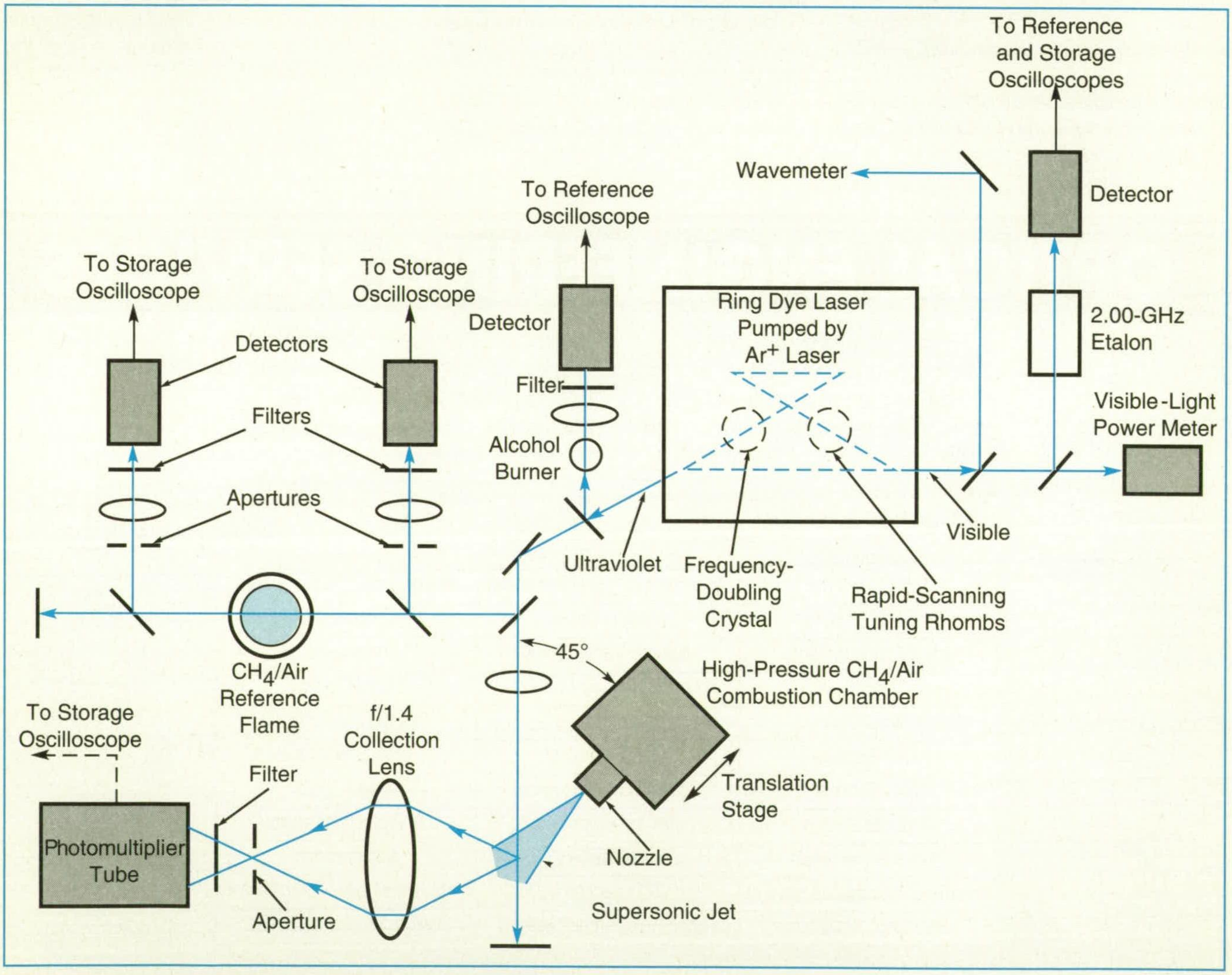
Lewis Research Center, Cleveland, Ohio

Mass flow rates of air and other gases would be computed from absorption-spectroscopic measurements of light generated by tunable diode lasers, according to a proposal. The development of the proposed method is motivated by the need for nonintrusive monitoring and control of mass-flow rates at various locations in the engines of advanced hypersonic airplanes. The method will likely be implemented with rugged, compact, economical lasers and with optical fibers to guide the laser light to and from the measurement locations. Depending upon the particular application, the method would yield path-arranged or spatially resolved data on the density, temperature, and velocity of flow of the gas in question. The product of density and velocity would be the mass flux.

In one version of the method, the wavelength of a narrow-band diode laser would be modulated across a range that contains one or more discrete absorption transitions of a molecular constituent of the flow. For example, the A absorption band of oxygen at wavelengths near 760 nm might be suitable for measurements of a flow of air. Compact, economical tunable solid-state diode lasers that operate in this wavelength range are now available.

The fraction of incident light transmitted through the gas probed by the laser beam would be measured as a function of wavelength and analyzed via Beer's law to infer the density of the absorbing species (e.g., oxygen). The temperature of the gas would be inferred, via the Boltzmann relation, from the ratio between the absorptions in two spectral lines. The speed along the line of sight would be inferred from the Doppler shift of the absorption spectrum relative to the absorption spectrum of a stationary sample of the gas. Of course, if the orientation of the flow were not known a priori, a complete determination of velocity would necessitate measurements of speeds along multiple (at least three) lines of sight.

The feasibility of the method was demonstrated in experiments in which



Absorption Spectral Lines of OH in a supersonic jet driven by combustion of CH_4 were measured, and the velocity, temperature, and pressure were inferred from the measurements.

the beam from a rapidly scanning ring dye laser probed two absorption spectral lines of the OH radical at wave numbers near 32,625 cm^{-1} (wavelengths near 306.51 nm) in a supersonic free jet driven by combustion of methane (see figure). The shapes of the absorption lines were recorded in spatially resolved, single-point fluorescence. The Doppler shift, ratio between intensities, and collision broadening of the lines were used to determine the velocity, temperature, and pressure.

This work was done by R. K. Hanson of Stanford University for **Lewis Research Center**. *For further information,* ***write in 26*** *on the Reader Information Request Card. LEW-15063*

Optical Correlator Performs Novelty Filtering

Correlation and novelty filtering take place in a photorefractive crystal.

NASA's Jet Propulsion Laboratory, Pasadena, California

An experimental real-time optical correlator performs novelty filtering in addition to correlation; that is, there is an increase in the correlation peak of an input image that matches a reference image when the input image is moving. (The correlation peaks of matched stationary input images in the same scene also increase by about the same amount: this may be advantageous or disadvantageous, depending on the specific application.)

The basic configuration of this correlator is that of a Vander Lugt optical correlator that includes a reflection grating formed holographically in a thick CdTe photorefractive crystal. Both correlation and novelty filtering take place in the crystal, but the principle of operation is different from that of a simple combination of a novelty filter with an optical correlator. Instead, the novelty-filtering aspect of the principle of operation is based on the dynamic-erasure property of the photorefractive crystal.

The source of light for the correlator is a neodymium:yttrium aluminum garnet laser operating at a wavelength of 1.06 μm. The laser beam is split into reading, writing, and reference plane-wave beams. As shown schematically in the figure, the Fourier transforms of the reference and input images are spatially modulated onto the writing and reading beams, respectively. The hologram is formed in the photorefractive crystal by interference between this modulated writing beam and the reference plane-wave beam. The correlation image is formed in the charge-coupled-device camera when the hologram is read by the modulated reading beam.

The principle of operation as described thus far is that of an ordinary optical correlator. However, the modulated reading beam containing the Fourier transform of the input image partially erases the grating in the crystal produced by the modulated writing beam and the reference plane-wave beam. This partial erasure reduces the intensity of the correlation peaks when the input image is stationary.

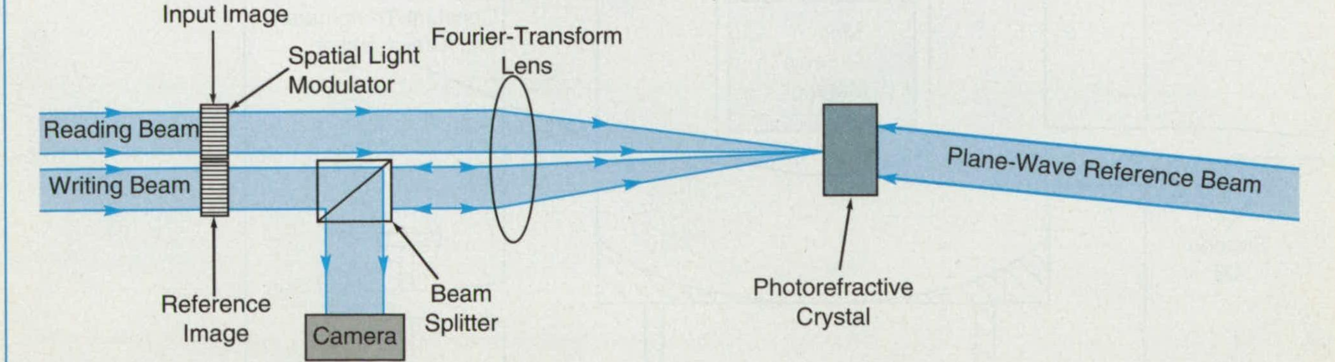
However, when the input image moves, the intersection of the Fourier transforms of the input and reference images also moves. As a result, parts of the grating that were not illuminated or were weakly illuminated by the reading beam become fully illuminated. These parts of the grating are stronger than the parts that were fully illuminated before, because these parts have not been partially erased. Consequently, the correlation peaks obtained from these parts are stronger for a short time until they become partly erased under full illumination by the reading beam. Because the degree of erasure reaches an effective equilibrium value in a finite time, the intensity of the correlation peak should depend on the speed of the input image.

The weaker correlation peaks from stationary matched input are still present. It may be desirable to suppress them in some applications to discriminate against stationary clutter and thereby aid identification of moving objects. This can be done by adjusting the contrast and brightness on the cathode-ray-tube video monitor on which the output correlation image is displayed.

This work was done by Duncan Tsuen-Hsi Liu, Tien-Hsin Chao, and Li-Jen Cheng of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 66*** *on the Reader Information Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office– JPL [see page 14].

Refer to NPO-18769.



This **Optical Correlator** performs novelty filtering (in addition to correlation) by virtue of the dynamic-erasure property of the photorefractive crystal. The crystal is oriented to enable cross-polarization diffraction, which, together with the polarizing beam splitter, may increase the signal-to-noise ratio. Not shown are the laser and the optical components that expand, collimate, and divide the laser beam.

Growing Organic Crystals by the Czochralski Method

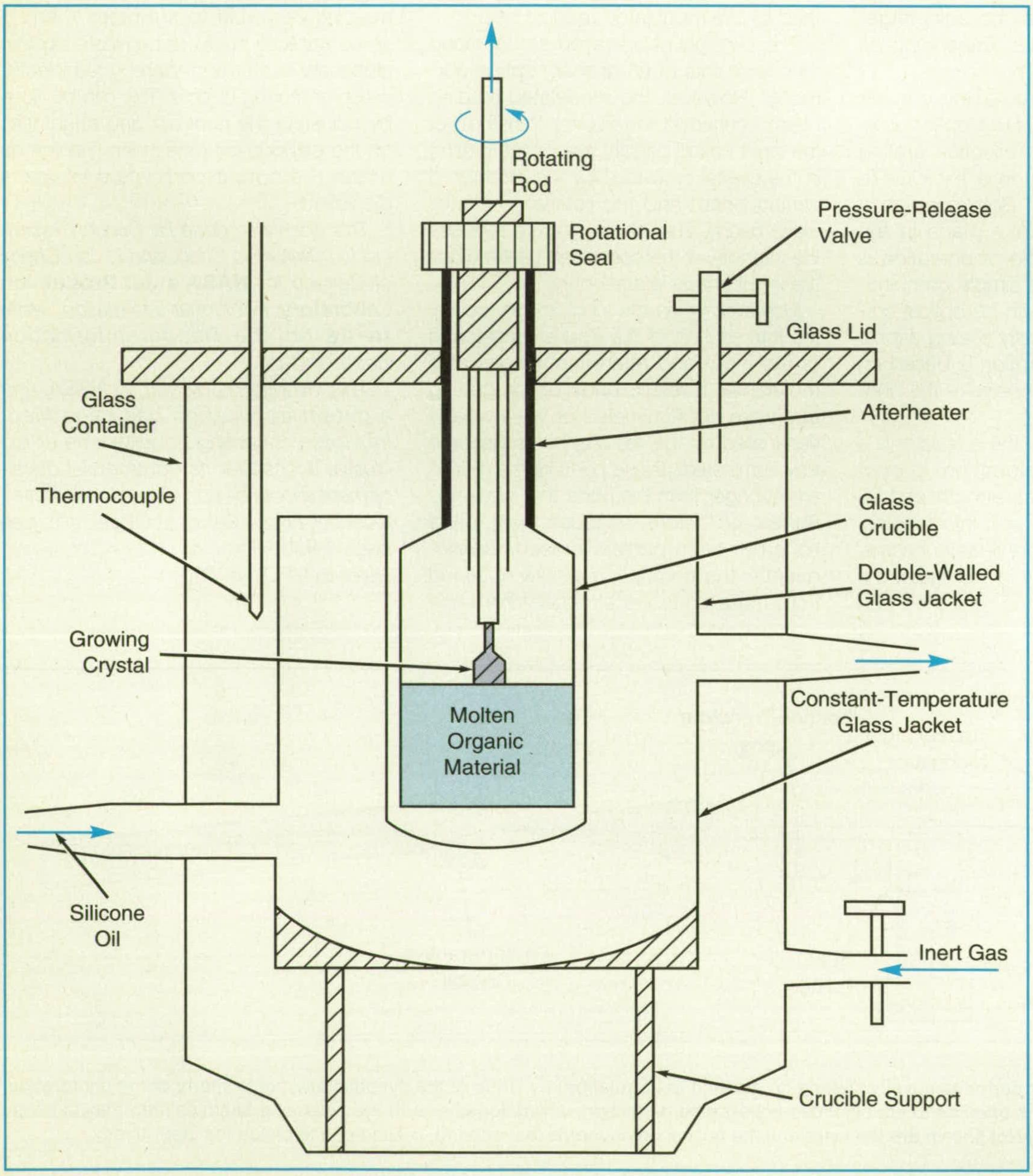
The traditional method for inorganic semiconductors is adapted to optically nonlinear organic materials.

Marshall Space Flight Center, Alabama

An apparatus grows high-quality single crystals of organic compounds by the Czochralski method, which has long been favored for the growth of inorganic semiconductor materials like silicon and gallium arsenide. The organic crystals in question have highly nonlinear optical properties that are well suited for advanced optoelectronic devices.

Until now, single-crystal organic materials have been grown from vapor or by the Bridgman technique. In these techniques, crystals would suffer damage as they solidified and came into contact with the walls of containers. However, in the Czochralski process, a growing crystal is lifted from the middle of the molten material without touching the walls.

Because of the relatively low melting temperatures of organic crystals, glass vessels can be used in this Czochralski growth apparatus. The melt, the growing crystal, and the solid/liquid interface can be seen through the vessels from almost



The **Glass Growth Chamber** reveals an organic crystal at all stages of its growth. The flowing hot oil maintains a constant temperature, within 0.1 °C, up to 250 °C.

any direction. The vessels are a glass crucible, a double-walled glass jacket that surrounds the crucible, and a cylindrical glass container that surrounds the double-walled glass jacket (see figure). Hot silicone oil is made to flow through the jacket to keep the organic material in the crucible molten at a constant temperature. Inert gas is made to flow through the container.

The container is capped at one end by a glass lid with a rotational seal at its center. Through the seal, a precisely ground glass rod with a seed crystal of the organic material at its tip is lowered to the surface of the melt. The rod is turned slowly and gradually pulled up from the melt, lifting a continuously solidifying single-crystal bar of the organic material with it. An afterheater prevents the organic vapor from condensing on the glass, helps to control the distribution of temperature in the crucible, and can be used to anneal the bar before it is removed from the apparatus.

This apparatus has been used to grow crystals of benzil ($C_6H_5COCOC_6H_5$), typically 10mm in diameter and 30mm long. The benzil is heated to a temperature of 97 °C (slightly above its melting temperature), while a seed crystal is rotated at 10 to 20 r/min and withdrawn from the melt at a rate of about 0.15 mm/h.

This work was done by Angela Shields, Donald O. Frazier, and Benjamin G. Penn of **Marshall Space Flight Center** *and M. D. Aggarwal and W. S. Wang of Alabama A. & M. University. For further information,* ***write in 45*** *on the Reader Information Request Card. MFS-26228*

Protective, Sacrificial Coats on Optical Surfaces

Contamination would be removed by erosion of the coats.

Lyndon B. Johnson Space Center, Houston, Texas

Clear, easily cleaned sacrificial coats of polytetrafluoroethylene, polyurethane, silicone, or other low-outgassing organic films can help to maintain the optical properties of the surfaces of radiators, solar panels, and other components by protecting them from physical damage and by eroding away. Originally, these coats were intended to protect the surfaces of radiators on spacecraft in low orbit around the Earth, where the impact of atomic oxygen at orbital speed erodes the coating material, thereby carrying away contaminants that have accumulated. On Earth, such coating materials might be used to protect optical surfaces against damage during manufacture or to protect and facilitate the cleaning of optical surfaces that are particularly delicate or that cannot otherwise be cleaned easily.

A typical clear, organic sacrificial coat could be applied by conventional spraying or other techniques. The coat could reside only on the surface or could, in addition, be partially absorbed into a porous substrate. Although the integrity of the bond between the substrate and the coat must be sufficient to prevent gross delamination, limited regions of unbond may not interfere with the performance of the coat.

In experiments, a variety of protective coating materials were applied to small samples, including aluminum samples coated with Z-93 paint. Optical measurements showed that the clear, transparent coats did not significantly alter the optical properties of these samples. Minor increases (about 0.03) in solar absorbance were measured when the thicknesses of protective coats ranged up to around 3 mils (0.08 mm). Normal emissivity was not affected. A limited number of peel tests indicated that the coats adhered acceptably to the substrates.

This work was done by Henry W. Babel, Mark M. Hasegawa, and Cherie A. Jones of McDonnell Douglas Corp. for **Johnson Space Center** *For further information,* ***write in 48*** *on the Reader information Request Card.*

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to the McDonnell Douglas Co. Inquiries concerning licenses for its commercial development should be addressed to

McDonnell Douglas
Richard Pressler
P.O. Box 516
St. Louis, MO

Refer to MSC-22052, volume and number of this Laser Tech Briefs issue, and the page number.
MSC-22052

Program for Thresholding in Digital Images

THRTOOL provides for a choice among four methods of thresholding.

The THRTOOL program applies thresholding techniques to Sun rasterfiles. THRTOOL uses a method called local thresholding, or variable thresholding, in which thresholds are set dynamically according to local characteristics estimated from the observed intensity histograms of overlapping blocks within a digital image. A box size in pixels is specified and then used to construct the overlapping blocks for thresholding. The sizes of the overlapping blocks are twice those of the boxes. The blocks are used to obtain the array of thresholds. For the interior of the image, the location of a pixel in a block is used to interpolate the array of the thresholds bilinearly and arrive at the threshold value for that pixel. The threshold value for a point on the exterior of the image is computed by use of the value from the closest point in the array of thresholds.

THRTOOL provides for a choice among four methods of thresholding: In the first method, the average pixel value of each block serves as an entry in the array of thresholds. In the second method, the array of thresholds is loaded with the median value from each box. The third method is the Otsu method, in which one selects the optimum threshold value by using a discriminant criterion function such that the separation between classes is maximized. In the fourth method, one selects a threshold value such that the moments in the original block are preserved.

THRTOOL is written in C language and has been implemented on Sun series and Silicon Graphics IRIS machines. Inasmuch as this package of software processes Sun rasterfiles, a graphical interface that supports the viewing of Sun rasterfiles would be helpful in visualizing results; however, the package will run without the viewing capability. The standard distribution medium for this package is a 0.25-in. (6.35-mm) streaming-magnetic-tape cartridge in UNIX tar format. It is also available on a 3.5-in. (8.89-cm) diskette in UNIX tar format or on a 0.25-in. (6.35-mm) IRIS tape cartridge in UNIX tar format. THRTOOL was developed in 1992.

This program was written by Scott R. Nolf, Elizabeth L. Avis, and Christine G. Matthews of Computer Sciences Corp. and Kathryn Stacy of **Langley Research Center**. *For further information,* ***write in 57*** *on the Reader Information Request Card.*
LAR-14958

Test Bed for Control of Optical-Path Lengths

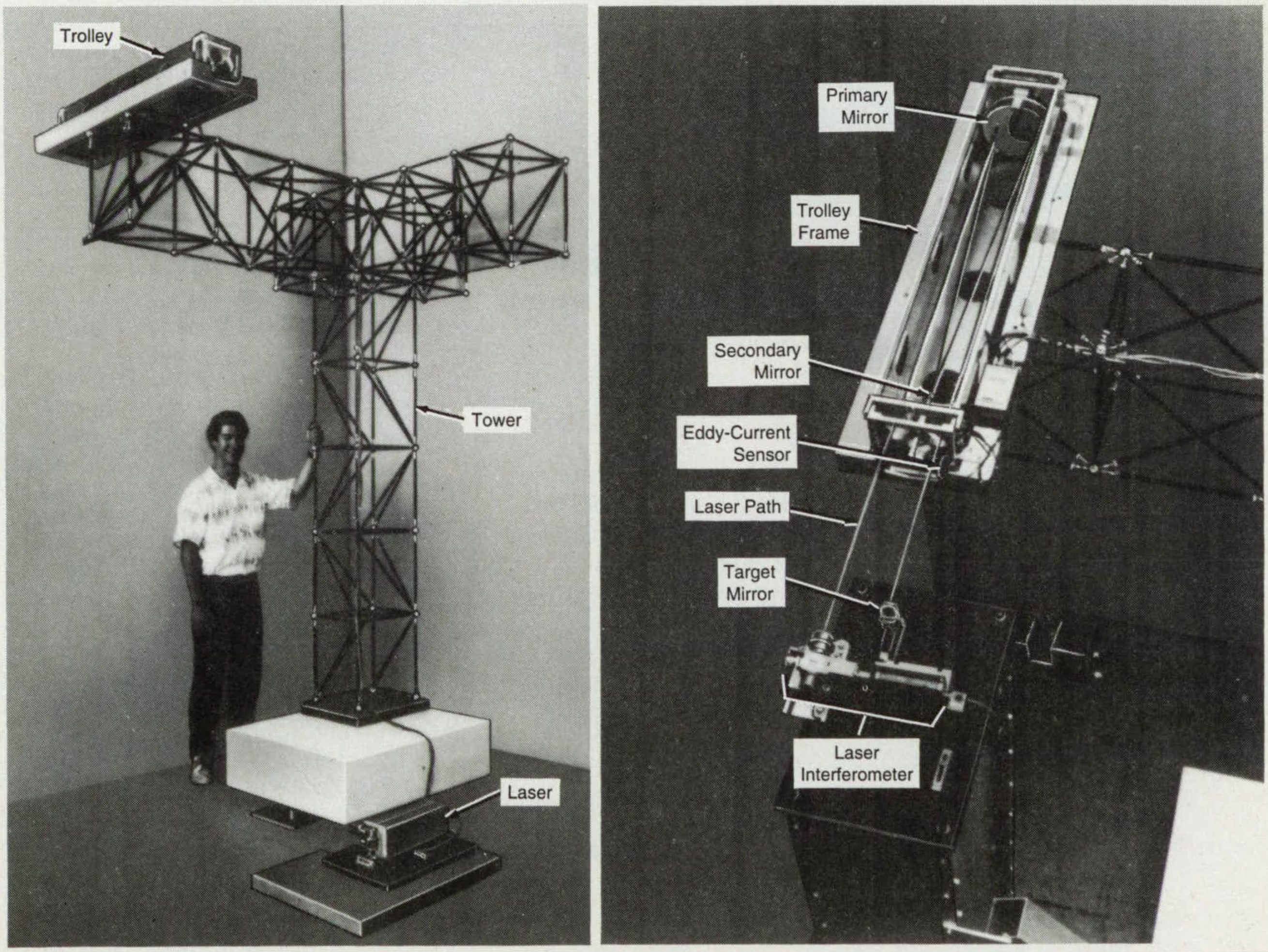
Experimental structure can be subjected to a variety of disturbances and corrections.

NASA's Jet Propulsion Laboratory, Pasadena, California

A truss structure and ancillary equipment constitute a test bed for experiments in methods of controlling the lengths of optical paths under conditions of structural vibration and deformation. The test bed accommodates both passive and active methods of control. The experimental control system can reduce millimeter-level disturbances in optical path length to nanometers. The equipment is being developed for control, alignment, and aiming of distributed optical systems on large flexible structures.

The test bed includes a tower 2.5 meters high with two horizontal arms extending at right angles from its top (see figure). It is rigidly mounted on a massive steel block that provides a measure of isolation from ground vibrations. The block rests on three adjustable jackscrews to level the block and prevent it from rocking on an uneven floor.

An optical motion-compensation system similar to one described previously in *NASA Tech Briefs* is enclosed in a flexure-mounted frame, called the "trolley," at the end of the longer horizontal arm. In its basic configuration, the trolley contains a cat's-eye retroreflector and primary and secondary mirrors to reflect light outward in a direction parallel to an incoming beam of light. The trolley frame is made of a nickel/iron alloy with low thermal



The **Trolley Is Mounted on One Arm** on top of the tower. The shorter arm is available for such additional optical elements as a corner cube reflector. In use, the laser and the other components of the interferometer shown on the floor in the left photograph are placed on another tower to direct light into the trolley, as in the right photograph. Inside the trolley are a variety of path-length-varying components.

expansion, with an aluminum connection between mirrors to create a thermally stable separation between them. The trolley is suspended from an aluminum base by flexure elements that give it a large measure of mechanical isolation from the rest of the test-bed structure. The aluminum base is bolted to the structure by a bracket, the stiffness of which can be varied to tune out local vibrational modes so they do not interfere with control.

A coarse optical-path-length compensation stage moves the entire trolley relative to its suspension. This stage contains a voice-coil actuator with a total stroke of 6 mm. This stage works best at vibrational frequencies below 100Hz.

A fine compensation stage moves the secondary mirror relative to the trolley frame. This stage contains a stack of two piezoelectric transducers: one with a stroke of 30μm and resolution of 10nm, the other with a stroke of 10μm and resolution of 1nm, respectively. An identical stack of piezoelectric actuators moves a counterweight in the opposite direction to neutralize the reaction.

More optical elements can be added to the test bed to couple structural motion into the path length more directly. For example, a target mirror can be placed on the trolley base, which moves with the structure, instead of on an adjacent, independent optical bench. For another example, light from a laser on the independent optical bench can be diverted to a corner cube on the other arm of the structure before it enters the trolley. For even more difficult experimental conditions, the stiffness of the trolley-mounting bracket can be changed to bring the local vibrational modes of the trolley-mounting bracket within the bandwidth of the control system.

The independent optical bench is a tower 2.7m high. It holds a heterodyne laser interferometer that measures the total length of the optical path to a resolution of 2.5nm. To suppress vibrations, the tower is designed for stiffness, and it rests on an energy-absorbing pad. The residual motions of the tower are small and well within the control bandwidths, and thus are treated merely as additional sources of disturbance.

Additional sensors are available for monitoring motions of the structure. Accelerometers can be placed almost anywhere on the trolley, structure, or laser tower. An eddy-current sensor on the trolley measures the displacement between the trolley and the rest of the structure.

A variety of actuators are also available, in addition to those on the trolley. These include struts that contain piezoelectric elements that vary their lengths, and passive damping struts, in which viscous liquid absorbs vibrational energy. Disturbance sources can be placed virtually anywhere on the structure and can act in any direction.

Single-board computers, augmented by single-board array processors, control the test bed. The computers sample the outputs of the sensors, compute control gains, and send control signals to the actuators to change the applied disturbances.

This work was done by Michael C. O'Neal, Daniel D. Eldred, and Dankai Liu of Caltech and David C. Redding of Charles Draper Laboratories for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 5*** *on the Reader Information Request Card.* NPO-18487

Laser-Based Tram Control for Mobile Mining Equipment

A guidance system uses inexpensive off-the-shelf laser sensors to control the movements of a 50-ton mining machine in an underground coal mine.

United States Bureau of Mines, Pittsburgh Research Center

Progressive technology has the potential to greatly improve mine-worker safety, helping to create a safer, better working environment for miners by keeping them away from the dangerous face area. One benefit of such technology is the remote computer-assisted operation of mining systems for underground, highwall and surface mining applications.

A cornerstone for computer-assisted operation is an effective guidance system. Since there are no guidance systems on any commercial continuous miners (CM's), a team developed and tested a laser-based sensor system based on a commercially available laser scanning sensor.

The laser-based guidance system employs four laser scanning sensors at fixed locations in a mine entryway to report the angular coordinates of two cylindrical retroreflective targets mounted on a CM. The laser scanner used in the system is the LN-120/40001 Lasernet, developed by Namco Controls of Mentor, Ohio. It uses an eyesafe Class II 2.0mW HeNe laser light source directed at a rotating mirror. The targets are retroreflective tape attached to the 10-inch-diameter, 18-inch-tall targets.

A real-time microcomputer system uniquely addresses and requests data from each Lasernet sensor. The microcomputer converts the raw data to angular coordinates, performs error correction, and uses triangulation to process the sensor data and update the position and heading of the CM five times per second. Using a simple control algorithm and communications interface to the CM actuation computer, the system also controls rotational and translational tram maneuvers.

Researchers first took the laser system underground in early 1991 and performed several experiments to determine system reliability and accuracy. Figure 1 shows the experimental setup in an underground mine. The Lasernet sensors are housed in specially designed explosion-proof enclosures to eliminate any possibility of dust ignition. The enclosures and lasers are mounted on two poles located at fixed positions on both sides of an entryway. Two cylindrical retroreflective targets are mounted on the tail end of the CM.

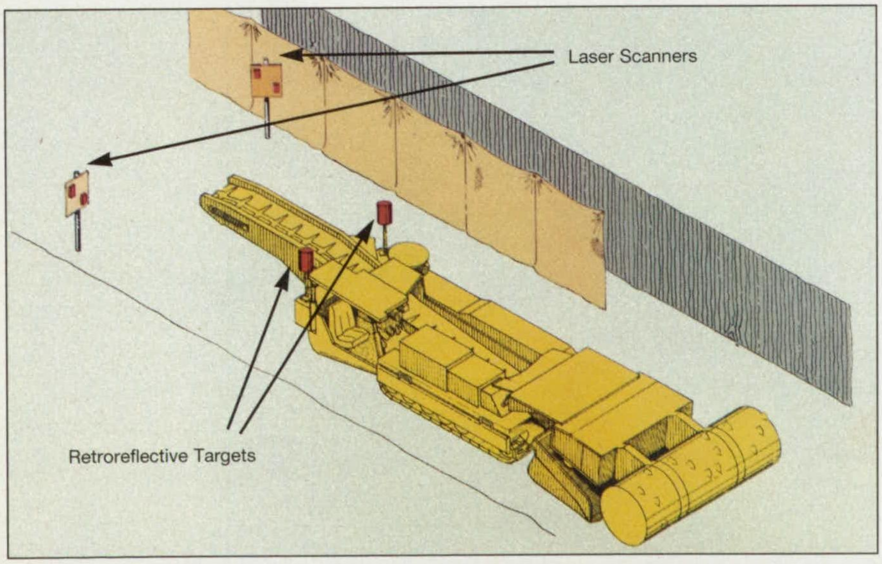


Figure 1. Conceptual drawing of **Lasernet guidance system** with targets on CM and Lasernet sensors in entryway.

The most crucial factor in maintaining the laser system's reliability underground is keeping the targets within the Lasernet sensor's field of view. The field of view is not only dependent on the range of the sensor, but also on the targets' vertical position with respect to the laser's horizontal scan of light. As the CM traverses the irregular mine floor, the scanning beam of the laser must continue to cross the target surface. By employing tall targets and four Lasernet sensors at different heights, the vertical tolerance was an acceptable 0.76 meter. An alternative solution for unusually irregular floors would be to add a mechanical mirrored assembly to the sensor which would sweep the beam vertically when no targets are detected.

The target detection range of the Lasernet sensor is an acceptable 10.67 meters. However, targets eventually become out of range as mining procedure progresses. The CM is constantly removing coal and advancing its position in the entry. Therefore a greater target detection range is most desirable because it would reduce the frequency at which the lasers would require advancement into the newly mined areas.

The data taken to determine the accuracy of the laser system in tracking position and heading and controlling the tram maneuvers of the CM underground was promising. A laser transit was used to verify the system accuracy as the CM performed a variety of maneuvers underground. Tracking error is less than 2.5cm in position and 0.5° in heading. Tram control error is less than 10.2cm translation and less than 2° rotation.

Related underground experiments on computer-assisted mining systems used the laser system to track and control the tramming of the CM. The laser system was an integral part of two experiments to test

the first fully controlled, automatic execution of multiple sump-shear cutting cycles. The first experiment used a preprogrammed coal removal script created and executed by the autonomous mining research and development system (AMREDS), a Windows-based computer program developed by the Bureau of Mines and Carnegie Mellon University. The second experiment used Carnegie Mellon University's MINENAV software to dynamically plan the maneuvers and appendage commands necessary during a two-pass mining sequence. Details are omitted here for brevity.

Results of the underground experiments show promise for application of this system in many mobile vehicle environments. The system can accurately track any target-equipped vehicle within the target detection range. For more mobile applications, the laser sensors can be mounted on-board the vehicle, and multiple pairs of targets off-board. Additionally, the laser/target configuration is adaptable for different applications. The four-laser, two-target configuration was found to be most reliable and accurate for the underground CM application. However, other configurations such as one-laser three-target were also implemented and tested.

This work was done by Donna L. Anderson of the **Bureau of Mines, Pittsburgh Research Center**. *For further information* ***write in 104*** *on the Reader Information Request card.*

Low-Flow-Rate Dry-Powder Feeder

Rates of flow are optimized for measurement of particle-size distributions.

Marshall Space Flight Center, Alabama

An apparatus feeds a small, precise flow of dry powder through the laser beam of an optical analyzer, which measures the patterns of light created by forward scattering (Fraunhofer diffraction) of the laser beam from the powder particles. From this optical measurement, the statistical distribution of the sizes of the powder particles is computed.

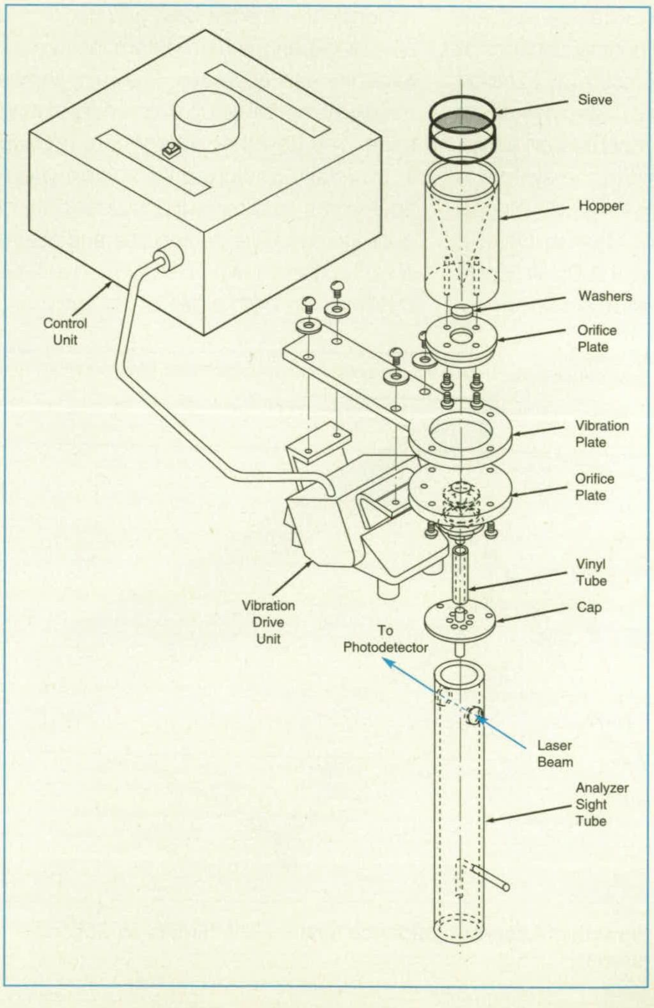
The powder-feeding apparatus provides the steady flow that is neither too dense nor too sparse for creation of the required diffraction patterns. Flow at too high a rate would be too dense in that it would result in multiple scattering; the optical analyzer would measure two or more particles at the same time and indicate a smaller particle than was actually there. Flow at too low a rate would be too sparse in that it would yield insufficient data for computation of the particle-size distribution. Too sparse a flow would also expose the photodetector in the optical analyzer to direct laser radiation in excess of its measurement range.

In the powder-feeding apparatus, the powder descends from a hopper through a series of orifices, which meter the flow. The subassembly that contains the hopper and metering orifices is vibrated to prevent bridging of orifices and thereby ensure steady flow at the maximum rate permitted by the orifices. After flowing through the lowest metering orifice, the powder stream continues downward through a flexible tube into a vertical analyzer sight tube, where the laser beam intercepts the stream monitored by the photodetector. The powder continues to flow down the sight tube and is collected at the bottom. The collected powder can be reused.

The rate of flow can be changed by replacing the metering orifices with other orifices of different diameters. Rates of flow usually range from 0.2 to 0.4 g/s depending on the bulk density and the particle-size distributions of the powders.

The feeder was developed for analyzing particle-size distributions of solid-propellant powders. The feeder could also be adapted to use in the pharmaceutical industry, in the manufacture of metal powder, and in other applications in which the particle-size distributions of materials are used to control rates of chemical reactions and/or physical characteristics of processes.

This work was done by Keith E. Ramsey of GenCorp Aerojet for **Marshall Space Flight Center**. *For further information,* ***write in 105*** *on the Reader Information Request Card. MFS-28738*



Powder Falls from a hopper through orifices, passing through a laser beam. A control unit regulates vibration to provide a slow, uniform flow.

Sol-Gel Optical Fibermaking with Removable Substrates

Eliminating the preform can simplify the process and reduce costs.

Fiber Optics Branch, U.S. Army Communications-Electronics Command, Ft. Monmouth, New Jersey

The standard low-loss optical fiber drawing process involves a glass cylinder preform about a half-inch thick and just a few feet long. The preform is then drawn into an optical fiber of a single or a graded index of refraction across its diameter. A novel process uses a continuously moving filamentary core on which are deposited layers of glass precursor coatings. The core material is either removed or becomes an integral part of the optical fiber. The process can produce extremely long lengths and does away with the batch-type handling needed with preforms.

In the process, the organic core filament moves past a number of stations. An early station coats the filament with one or more shells of a glass-forming material known as sol-gel. After densification, the glass fiber gets a protective coating and is reeled out on a storage reel. Thus the only limitations on fiber length are the reel capacity and the precursor core's length. Since the core can be supplied from a continuously operating extrusion source, it can be of almost any length. This results in substantial cost reduction at the same time that it produces a fiber with excellent optical quality and high mechanical strength.

The sol-gel process classically offered two approaches to making optical fibers. The first involves the controlled hydrolysis of metal alkoxides, either for direct fiber drawing of short lengths from solution, or for casting porous preforms. The second involves the dispersion of colloidal particles, in either an aqueous or a nonaqueous solution. Both approaches are silica-based.

Still another approach involves coating a shell or concentric shells of sol-gel glass on a fiber of graphite or plastic. The carbon host is sacrificed, and the glass shell is collapsed to a fiber. It is a three-step process. In the first, the fiber may be dipped repeatedly to build up a series of films that gel. The second step is drying of the silica shell. The gel converts largely to oxide, and a rigid continuous shell runs the length of the fiber. At the same time the shell is shrinking in the radial dimension, it must remain intact along the axis of the fiber. Repeated observation showed that thin films shrink perpendicular to the substrate and not in the plane of the substrate.

The third step is the complete collapse of the shell. It is possible to densify the shell by controlled heating in oxidizing atmospheres followed by vacuum treatment to pull out any remaining water vapor or gases. The ultimate temperature is below the softening temperature for the glass, and the fiber therefore does not need support during firing. This eliminates sources of contamination and surface abrasion. Nevertheless the temperature is high enough to permit formation of highly densified glass.

There is no inherent limitation in the sol-gel material that restricts its use in lightwave communications. The volatile-host method, in which volatilized carbon or graphite core materials are ultimately removed from the fiber, produces a fiber that competes with commercial fibers produced by chemical vapor deposition.

The filament may also consist of a material that, rather than being removed from the fiber, becomes an integral part of it. Thus, a refractory oxide such as alumina, zirconia or tantalum pentoxide can be used as the core. Additionally the filament can be a material that chemically converts into an integral portion of the final fiber. These cores are halide-containing filaments such as $ZrF4$, $AlF3$, and KCl.

Another embodiment of the method can produce fiber optic solid-state devices, lasers, or amplifiers through the introduction of compatible dopant ions into the sol-gel structure. For example the fiber could be doped with erbium and vitrified into an optical amplifier. A one-meter length of such a fiber amplifier could, from calculation, produce a gain of 30 dB at a frequency of 10 GHz. Such a device has obvious application in undersea cables, reducing both the power required and the number of components in comparison with conventional electro-optical amplifiers; life and reliability should improve.

This work was done by Robert O. Savage, Robert J. Fischer and Sam Divita of the Fiber Optics Branch of the Space and Terrestrial Communications Directorate, **U.S. Army Communications-Electronics Command,** *Fort Monmouth, New Jersey. For further information, contact Sam Divita at (908) 544-4490.*

This invention is owned by the U.S. Army and a patent (no. 5,114,738) has been granted. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Fort Monmouth; (908) 542-3062.

Making Rectangular Apertures in Silicon

Precise photolithography yields apertures of superior geometry.

Goddard Space Flight Center, Greenbelt, Maryland

Conventional silicon micromachining techniques produce micrometer-sized rectangular apertures. The apertures are used to define source and detector openings for measurements of images and scattered light in the visible, ultraviolet, and soft x-ray wavelength regions, and as general-purpose optical slits or slit arrays.

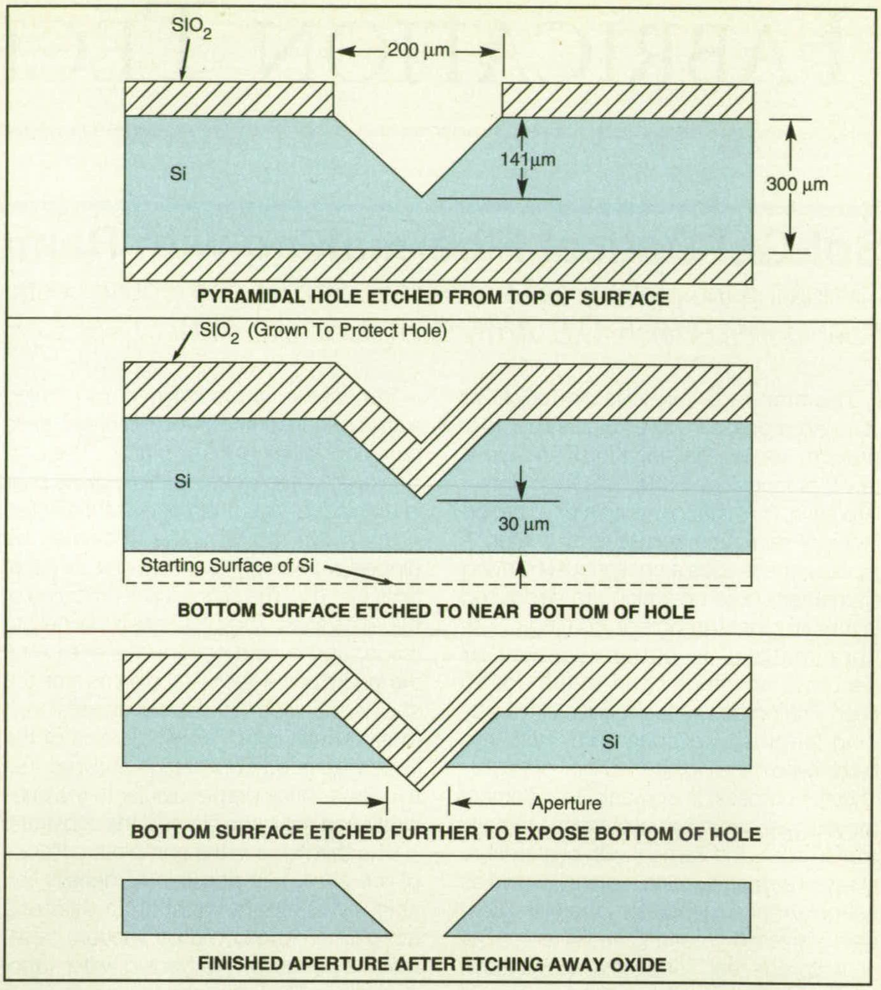
The rectangular microscopic apertures can replace circular pinholes made by puncturing foils with needles, or more recently by drilling foils with intense, highly-focused laser beams. The rectangular hole shape is important in raster-scan image detection schemes where rectangular apertures provide more complete spatial sampling than circular apertures do. Moreover, because the apertures are

made of silicon, which is rigid and has a low coefficient of thermal expansion, they are less affected by changes in temperature or pressure differentials than are foil apertures. In addition, the smooth, polished silicon surfaces reject uncollected light in a very predictable manner. In raster-scanning image dissection, the rectangular apertures in silicon can be used to achieve spatial resolution much finer than that achievable with charge-coupled-device (CCD) arrays because the silicon apertures can be made much smaller than the CCD picture elements (pixels).

The starting material for fabrication of an aperture is a 1-0-0 crystalline silicon water typically 300µm thick. By a series of photolithographic, oxidation, and chemical etching steps, a pyramidal or wedge-shaped hole is made in one side of the wafer. The wafer is eventually uniformly etched from the other side until the bottom of the hole opens. The opening is rectangular (instead of rounded) because silicon etches along preferential planes. Etching is continued until the opening at the bottom of the hole has the desired size. Of course, many such apertures can be formed simultaneously in the same wafer.

Apertures as small as 1.4 by 1.7µm have been made by this method. An array of about 100 such apertures would fit in the 20 x 20-µm area of a typical CCD pixel.

This work was done by Douglas B. Leviton, Murzy D. Jhabvala, Brent Mott, and Sridhar Manthripragada of **Goddard Space Flight Center.** *For further information,* ***write in 70*** *on the Reader Information Request Card.*
GSC-13529



Four of the Many Photolithographic Steps illustrate the fabrication of a typical rectangular aperture in a silicon wafer. A pyramidal hole is etched into the top side of the wafer. The other side of the wafer is etched away until it is only 30 to 50µm away from the bottom of the hole. Bottom-side etching is then continued gradually to expose an aperture of the required dimensions. Finally, the oxide protecting the top of the wafer and the pyramidal hole is etched away, leaving only silicon.

Imaging the Leading Edge of a Weld

The welding torch could be aligned better with the joint.

Marshall Space Flight Center, Alabama

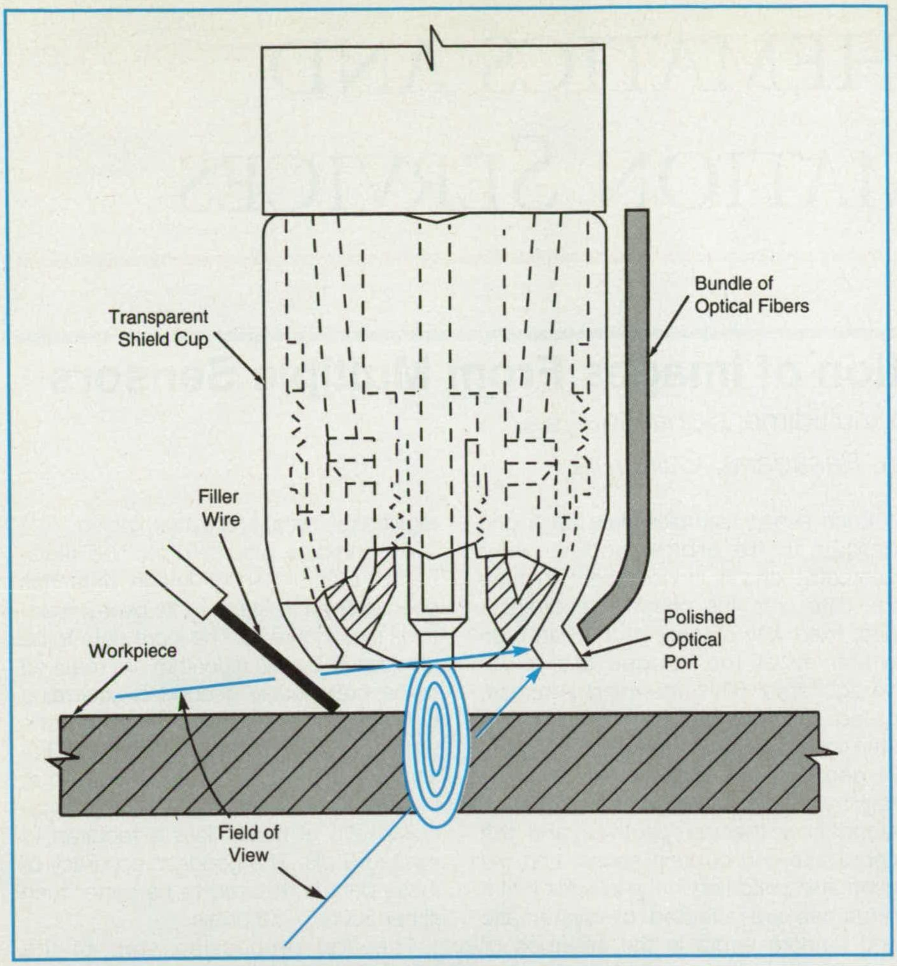
A proposed optical system integrated into a plasma arc welding torch would provide an image of the leading edge of the weld pool and the welding-arc-initiation point. Because a mass of molten metal does not obscure the leading edge of a typical weld pool, the edges of the workpieces to be welded together would be clearly and continuously visible in the image. A technician or robot could use the image to keep the high-density arc column centered on the joint, as is necessary to form a weld of high quality.

The system would include a coherent bundle of optical fibers and a transparent torch cup (see figure). One end of the fiber-optic cable would be aimed toward the weld joint through a polished optical port on the cup. The bundle of optical fibers would carry the image of the joint to a video camera, video-signal processor, and monitor. A weld controller would use the image to track the joint, control the feed and location of filler wire, and provide geometric data on the weld bead for real-time control of the welding process.

The proposed image-based control method offers important advantages over such current methods as through-the-arc sensing of parameters, identification of the surface of the base material, interpretation of eddy currents passed through the base material, and physical contact for control based on touch and feel. These methods can be inaccurate and unreliable and have caused expensive mistakes. Moreover, they require relatively complex, expensive, and obtrusive equipment, whereas the imaging technique would entail the use of a low-profile bundle of optical fibers with commercially available video and data-processing equipment.

This work was done by William F. McGee and Daniel J. Rybicki of Martin Marietta Corp. for **Marshall Space Flight Center.** *For further information,* ***write in 94*** *on the Reader Information Request Card.*

This invention is owned by NASA, and a patent application has been filed.



The **Bundle of Optical Fibers** would provide a remote view of the filler wire, weld puddle, and unwelded part of the joint through a polished port on the transparent shield cup. The transparent cup would also facilitate adjustment by revealing components that would be hidden behind an opaque cup.

Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14].
Refer to MFS-28797.

Mathematics and Information Services

Automated Registration of Images From Multiple Sensors

Fine registration is prerequisite to multidimensional analysis.

NASA's Jet Propulsion Laboratory, Pasadena, California

Images of terrain scanned in common by multiple Earth-orbiting remote sensors would be registered automatically with each other and, where possible, on a geographic coordinate grid, according to a proposal. Examples of the remote sensors in question include synthetic-aperture radar systems, infrared radiometers, and optical systems (e.g., cameras) that produce images in various wavelength bands in the visible, infrared, and centimetric parts of the spectrum. To derive geophysical parameters of scientific interest from these images, it is necessary to subject the image data to synergistic multidimensional analysis. Automation is needed to handle the accumulating mass of multisensor image data in providing the fine registration that is prerequisite to multidimensional analysis.

Each sensor samples data on a grid unique to its orbital and viewing geometry, and it is necessary to map the data onto the common coordinate grid, fixed with respect to the Earth, on which all of the images are to be coregistered. This mapping process, called "geocoding," is the first major step in the overall registration process. In geocoding and in the rest of the registration process, one must understand how the perspectives and the coordinate grid of each sensor and the geometric distortion in the images that it produces are affected by systematic and random errors in the assumed or measured positions and orientations of the sensor. Other factors that must be considered include the different spatial resolutions of different sensors, the availability of tie points or other ancillary registration data, and system noise.

A candidate algorithm for fine registration of multisensor image data has been defined in terms of its overall functions (see Figure 1). The input data to be processed by this algorithm are required to be preliminarily geocoded according to the best available information, and the preliminarily geocoded data from all the sensors are required to be resampled at the same pixel spacing. The signal-to-noise ratio of these data is required to exceed 5 dB. The geodetic accuracy of these data is required to be better than either 500m or 50 pixels.

The first processing step of the candidate algorithm would include the automatic selection of subframes from each input image to define local areas of multisensor coincident scanning where precise registration could be performed

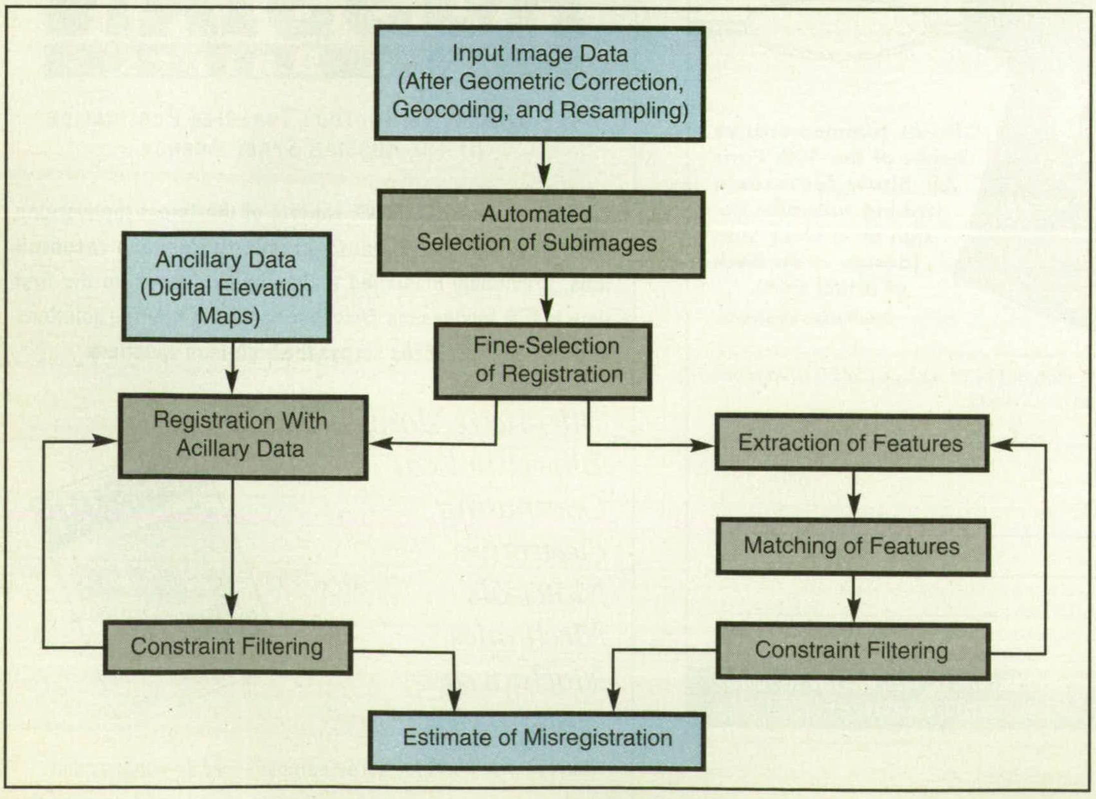


Figure 1. The **Multisensor-Registration Algorithm** provides for two alternative registration modes, depending on whether ancillary data are available.

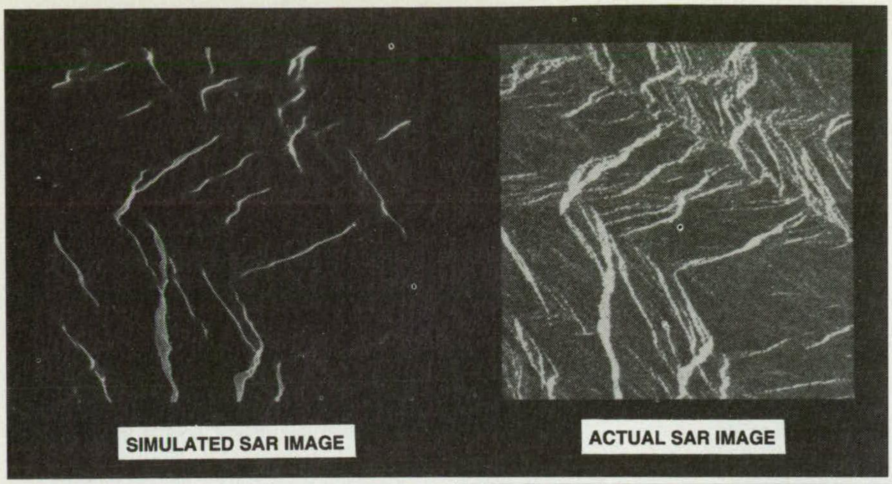


Figure 2. A **Simulated Image** of the terrain viewed by a sensor (in this case, synthetic-aperture radar) can be computed from the ancillary data (in this case, a digital elevation map), the viewing geometry, and a mathematical model of the physics of imaging (in this case, radar backscatter). In the proposed registration algorithm, the simulated and actual sensor images would be matched by use of an area-correlation technique.

with high confidence of success. Depending on the availability of ancillary data (for example, digital elevation maps derived from topographic maps or other sources), a registration mode would be selected. If a digital elevation map were available, the multisensor data would be coregistered to the common grid provided by the digital elevation map (see Figure 2). If a digital elevation map were not available, invariant features would be extracted from the subimages by use of well-known digital image-processing techniques, and correspondence would be established across the data to be registered.

To reduce the computational complexity of the algorithm and obtain several estimates of the misregistration per subimage, features would be matched at multiple locations, and the results filtered to evaluate their relative spatial consistency within the selected patch (this procedure is called "constraint filtering"). If the match could be labeled as statistically significant in the sense that it satisfied some quantitative measure of goodness, the misregistration error of the selected subimage would be estimated, and the multisensor data would then be registered. Otherwise, the result would be rejected, and the selection-and-matching process repeated with different parameters.

At a higher level of processing, the combined results from different features and from registered neighborhood patches could be used to produce a more accurate and more reliable solution. In effect, one could establish a cooperative process in which the results from different stages of processing would be used as reinforcements for the entire process.

This work was done by Eric J. M. Rignot, Ronald Kwok, John C. Curlander, and Shirley S. N. Pang of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 49*** *on the Reader Information Request Card. NPO-18336*

BOOKS AND REPORTS

Measuring Roughnesses of Optical Surfaces

Fine surface features can be measured by scanning tunneling microscopy and atomic force microscopy.

A report discusses the use of scanning tunneling microscopy and atomic force microscopy to measure the roughnesses of optical surfaces. These techniques offer greater spatial resolution than do such other techniques as mechanical profilometry, optical (noncontact) profilometry, and optical scatterometry.

A scanning tunneling microscope can be used to characterize the topography of an electrically conducting surface like that of a metal substrate or metallic coating on an electrically insulating substrate. It senses variations in the quantum-mechanical-tunneling current of electrons between the surface and a tungsten or platinum electrode as the electrode is scanned across the surface in a raster pattern. The tunneling current falls off sharply with distance and thus provides a measure of the roughness of the surface.

An atomic force microscope can be used to characterize an electrically insulating surface like that of a glass substrate. It includes a silicon nitride tip at the end of a cantilevered arm. Atomic forces (Van der Waals or electrostatic) between the tip and the surface deflect the arm to an extent that decreases sharply with distance. A topographical map of the surface can thus be generated by measuring the force on the arm as it scans a specimen.

The report describes representative applications of scanning tunneling microscopy and atomic force microscopy. The report notes that, while some mechanical profilometers can resolve surface-height variations over a spatial scale as small as 0.1µm, scanning tunneling microscopes and atomic force microscopes can resolve down to 1nm.

This work was done by Daniel R. Coulter, Gahnim A. Al-Jumaily, Nasrat A. Raouf, and Mark S. Anderson of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Scanning Tunneling Microscopy and Atomic Force Microscopy: New Tools for Characterization of Optical Surfaces and Coatings at Very High Spatial Frequencies,"* ***write in 86*** *on the Reader Information Request Card.*
NPO-18857

Extraction of Emissivities From Thermal Infrared Spectra

Two techniques for processing multispectral data are compared.

A report presents an evaluation of two techniques for extracting information on infrared emissivities from measurements

of radiance in six wavelength bands from 8 to 12μm. Emissivities in this wavelength region vary with the chemical compositions and physical structures of minerals and thus could be useful in remote mineralogical mapping of the surface of the Earth. The problem in extracting emissivity data from measured spectral radiances is to separate the effects of temperature from the effects of emissivity.

One of the techniques for extraction of emissivity data is called "model emittance calculation." This technique is based on the assumption that the emissivity of the entire surface in the longest wavelength band is fixed at a value of 0.93.

The other technique for extraction of emissivity data is called "thermal log residuals." This technique is based on the Wien radiation law, which is an approximation of Planck's radiation law. The equations show that this difference, called the "thermal log residual," depends only on a combination of emissivities; that is, it is independent of temperature.

Infrared-image data for use in evaluating the two techniques for extracting emittance data were acquired by NASA's airborne Thermal Infrared Multispectral Scanner (TIMS) over Cuprite, Nevada in wavelength bands of 8.83 to 9.47, 9.28 to 10.24, 10.11 to 11.20, and 10.88 to 11.65μm. The raw measured spectral radiances were calibrated with respect to black bodies at known temperatures in the TIMS, and corrected for atmospheric effects. The calibrated, corrected spectral radiances were then processed by use of the two techniques.

The technique of thermal log residuals was found to offer two advantages and one disadvantage in comparison with the technique of model emittance calculation. The first advantage is apparent even without examination of specific data: the thermal log residuals yield emissivity data in all six wavelength bands, whereas the thermal emissivity calculation yields emissivity data in only five wavelength bands (because the emissivity in the longest-wavelength band is assumed). The second advantage of thermal log residuals is that noise in one wavelength band does not affect the emittance data extracted from the other bands. In contradistinction, if the longest-wavelength band contains noise or if the assumed emissivity in this band is incorrect in the model emittance calculation, then noise is introduced into the emissivities in the other wavelength bands. The disadvantage of thermal log residuals is that the emissivity data computed by this technique cannot be compared easily with emissivities measured in a laboratory, whereas the results of model emittance calculations can be compared easily with laboratory data.

This work was done by Simon J. Hook and Anne B. Kahle of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Techniques for the Extraction of Emissivity Variations From Multispectral Thermal Infrared Data,"* ***write in 53*** *on the Reader Information Request Card.*
NPO-18438

Lidar Measurements of Stratospheric Ozone

Differential-absorption lidar has measured concentrations at altitudes up to 50km.

A report describes selected aspects of the underlying theory, design, and operation of a ground-based, high-power, pulsed lidar system that measures the concentration of stratospheric ozone as a function of altitude. The system is located in the San Gabriel Mountains in Southern California at an elevation of 2.3 km, where it has been operating since January, 1988.

The measurements taken by this system complement those taken by satellite-, rocket-, and balloon-borne instruments — in effect, serving as ground truth for the data acquired by those instruments. The system is being refined in iterative cycles of measurements, analysis of data, and modification of equipment. The accumulation of a substantial data base in continuing operation should lead to the capability for sensitive detection of trends in the concentration of ozone and for early warning of changes in the stratosphere.

The basic principle of operation is that of differential-absorption lidar. Laser pulses are generated at two wavelengths and transmitted simultaneously along the same approximately vertical path into the atmosphere. The wavelengths are chosen so that electromagnetic radiation at one of the wavelengths (in this case, 308nm) is absorbed strongly by the chemical species of interest (in this case, ozone) while the absorption by the species of interest at the other wavelength (in this case 353nm) is much weaker.

This work was done by I. Stuart McDermid, Sophie M. Godin, and T. Daniel Walsh of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Lidar Measurements of Stratospheric Ozone and Inter-Comparisons and Validation,"* ***write in 72*** *on the Reader Information Request Card.*
NPO-18437

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Leonard A. Ault
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The PIPT-X **optical isolators** from Isowave, Dover, NJ, are designed to enhance the performance of single-mode fiber optic systems by reducing optical feedback. Passive, non-reciprocal pigtailed devices, they are insensitive to light polarization. They are available in four configurations providing peak isolation of more than/equal to 40dB, 38dB, 35dB, and 30dB and peak insertion loss of less than/equal to 0.6dB, 0.8dB, 1.0dB, and 1.5dB at center wavelength and 23 °C. Wavelength options are 1290-1320nm and 1530-1560nm.

For More Information Write In No. 778

The X-Dap **fiber optic spectrophotometer** from Polytec PI, Auburn, MA, has no moving parts and offers stabilized repeated measurements. The light source has tungsten-halogen and deuterium lamps for VIS/near-IR and UV ranges respectively. The lamps can be run simultaneously. A random access mode unique to the X-Dap allows sampling of individual diodes in the 1024-element array detector at a rate of 25 microseconds/diode. The instrument can do PLS, colormetrics, and multicomponent analysis.

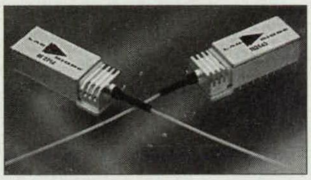
For More Information Write In No. 779

EG&G Reticon, Sunnyvale, CA, announces what it calls the world's first **solid-state industrial-scientific HDTV camera**, the MC4013. With a 1024 X 1024-pixel CCD photoplane and a 13.5-micron-square pixel design, the MC4013 is suitable for computer-based image processors. Progressive scan operation permits all pixels to be exposed at the same time, eliminating the time difference between adjacent pixels. The camera measures 2 1/4" X 2 /14" X 1 3/4", and is ruggedized for 300g shock and 30g vibration. The company supports the MC4013 with all accessories.

For More Information Write In No. 780

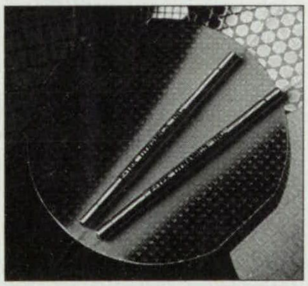
Laser Diode, Edison, NJ, enters the Fiber Distributed Data Interface (FDDI) market with the Models TS-2143 and RT-2714 FDDI **transmitter and receiver**. The transmitter is packaged in a hermetic Kovar 16-pin direct in-line package and is coupled directly by multimode fiber pigtail to a 1300nm surface-emitting LED. The receiver has an InGaAs PIN photodiode with ECL/PECL output directly fiber-coupled, and comes in a similar package. Temperature operating range of -40 to +110 degrees C is available.

For More Information Write In No. 723



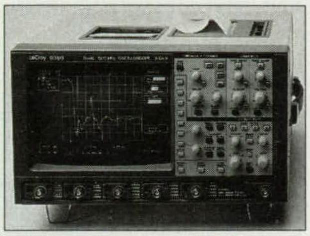
E-TEK Dynamics, San Jose, CA, announces that its **single-mode and multimode couplers** have the lowest possible polarization dependence loss available. They meet Bellcore specifications and are mass-producible. Other characteristics are low insertion loss (3.4dB for the premium model), temperature and humidity stability, and shock resistance. Premium, A-grade and B-grade single-mode 1X2 and 2X2 models are available at center wavelengths of 633, 830, 980, 1310, 1480, and 1550 nanometers.

For More Information Write In No. 724



PowerSpectra, Sunnyvale, CA, is offering the new POS904 series integrated **pulsed laser and driver** in a TO-5 can. It combines a 904nm quantum-well laser diode with the company's proprietary GaAs high-power switching technology in a windowed can. Peak power is 25W for a single diode and 70W for a three-diode stack. Both provide 5ns pulses at repetition rates up to 10kHz. Inputs required are +300VDC and a separate TTL control signal. No special external recharge circuit is needed.

For More Information Write In No. 725

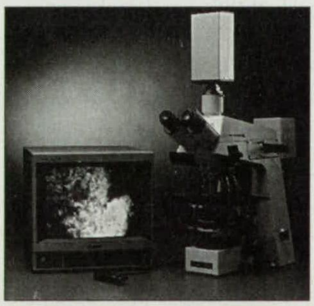


LeCroy, Chestnut Ridge, NY, has upgraded its Model 9360 two-channel **digital oscilloscope** with the addition of a 33MHz 68030 processor board that it says makes all facets of operation 2-3 times faster. The original version captured signals at a 5Gsec/sec sampling rate in real-time single-shot mode, with a 200psec spacing between time bins for high resolution. The 9360 gives automatic measurement of laser pulse amplitude, width, area, rise and fall time, and other parameters. It will capture and store every pulse up to a 30Hz repetition rate and average pulses at a 50-200Hz rep rate. A built-in 3.5" DOS floppy facilitates transfer of waveforms or pulse parameters. All purchasers of the Model 9360 will receive the new processor free, and it is standard for the current $12,490 price.

For More Information Write In No. 726

The ImagePoint video-format **CCD camera** from Photometrics, Tucson, AZ, has Peltier cooling and digital electronics to yield images with what the company calls significantly higher spatial resolution, lower noise, and larger dynamic range than traditional video cameras. ImagePoint's on-board memory enables full-motion video and freeze-frame output without an additional frame grabber. It can integrate over long exposures for improved signal-to-noise ratios. ImagePoint also can utilize 16 built-in lookup tables to provide contrast enhancement to view faint images on the video monitor. Photometrics says ImagePoint's ease of operation suits it for a wide range of optical microscopy, biological, densitometry, and surveillance tasks.

For More Information Write In No. 727



The new Laser Gauge from Keyence, Fair Lawn, NJ, is a **laser displacement sensor** for noncontact measurement of height, width, length, and thickness in inspection, assembly, production, and quality control. Real-time measurements to an accuracy of 0.1mm over a range of 80mm +/-20mm are possible no matter the target color or texture. Dimensions are 4.2" X 2.5" X 0.8". Calibration can be done locally or remotely using Keyence's One-Touch pushbutton calibration feature.

For More Information Write In No. 728

Ortel, Alhambra, CA, calls its new 3620 series of **CATV lasers and board assemblies** offering up to 16mW of output power an industry first. A complete fiber optic transmitter subassembly designed for OEMs, the series is available in 600MHz (Models 3620B and 3620D) and 860MHz (Model 3620C) versions for US and international frequency plans. These products include a 1310nm distributed feedback laser and an RF predistorter board. Internal components include an optical isolator, TE cooler, monitor photodiode, and thermistor.

For More Information Write In No. 729

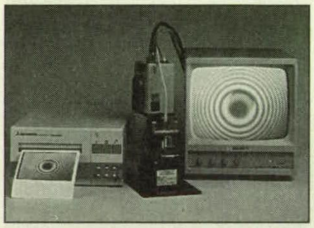
Marchand Electronics, Webster, NY, offers the PM22 **power amplifier module**. Its 75W linear amp can be used for driving synchronous motors, AC and DC motors, solenoids, and other precision power loads such as polygon laser scanners. The PM22 is built on a single 3" X 5" circuit board. Maximum output is +/-45V and 8A, and frequency response is DC-50kHz.

For More Information Write In No. 781

NEW PRODUCT SHOWCASE

The Connect-Chek **Interferometer System** XL from Norland Products, North Brunswick, NJ, integrates a fiber interferometer measuring 4" X 5.2" X 1.65" with a solid-state CCTV camera, 9" video monitor, and video printer. The unit measures key physical parameters of fiber optic connectors, including curvature radius, offset of polish to the fiber center, and the amount of fiber undercut or protrusion from the connector ferrule. It also can determine the quality of a polished connector. Norland provides all cables and adapters needed to connect the system as well as a Versamount adapter for evaluating ST, FC, and SC connectors.

For More Information Write In No. 730



The first of a new line of gallium arsenide devices from OKI Semiconductor, Sunnyvale, CA, the FET **Monolithic Microwave IC** (MMIC) broadband feedback AGC amplifier has a useful signal range to over 5.4GHz. Flat gain from below 800MHz to more than 4GHz makes the device suitable for narrowband and broadband IF and RF amplifiers in the L, C, and S bands. Fifty-ohm input and output are well matched for stable performance. The MMIC operates from a single 5V power supply.

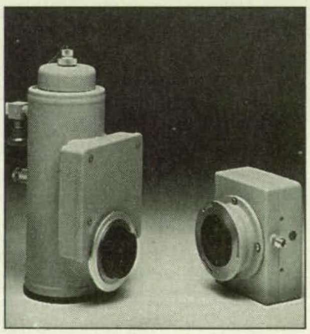
For More Information Write In No. 731

Anritsu Wiltron introduces the MW9070A **mini-optical time domain interferometer** that it says is the first of its size to allow the user to add different optical wavelength modules or multimode modules in the field. It detects fiber faults, points of high reflection and far end points, and measures splice and connector losses down to 0.1dB. Dynamic range is 23.5dB. The mini-OTDR measures 194 X 290 X 75mm and weighs 7 lbs.

For More Information Write In No. 732

Lasermetrics Division of FastPulse Technology, Saddle Brook, NJ, introduces its Series 5046 **electro-optic systems** for mode-locked pulse extraction and regenerative amplifier seeding. They are useful for laser pulse chopping, gating and slicing, and for pulse extraction with either continuous-wave or pulse-pumped lasers. Shown is a system incorporating a new high-voltage pulse driver capable of operating at up to 8kV and as low as 250V, making half- and quarter-wave voltage operation possible with no degradation of rise/fall times. Proprietary circuits provide adjustable-width pulses of 3ns rise and fall times and up to 10kHz repetition rates. Prices range from $11,000-$13,500 depending upon the light modulator and accessories.

For More Information Write In No. 733



A versatile line of **CCD cameras** from Princeton Instruments, Trenton, NJ, can detect x-ray images across the 30eV-100keV range. Various formats are available: thinned back-illuminated direct-detecting CCDs for 30eV-8keV; front-illuminated direct-detecting CCDs for 1keV-12keV; deep-depletion direct detecting CCDs for 1keV-30keV; phosphor-coated CCDs or phosphor-coated optical fiber minifiers for indirect detection from 8keV-70keV; and light-scintillating optical fiber minifiers for indirect detection of 50keV-100keV. Dynamic range is up to 17 bits with scan rates to 1MHz. Cooling is TE or cryogenic, and vacuum or atmospheric interfaces are available for the line.

For More Information Write In No. 734

Ophir Optronics, Peabody, MA, is offering the handheld Model Nova in its LaserStar Series of **laser power/energy meters**. The display is a 32 X 122 dot matrix supertwist LCD electroluminescent backlight, with a variety of analog and digital screen options for laser tuning, energy measurement, pyroelectric exposure and other functions. With appropriate heads measurements from nW to kW and microjoules to 200J can be made. With Ophir's Smart Connector technology, simply plugging in the head configures and calibrates the instrument.

For More Information Write In No. 735

Industrial Laser Technology, Clinton Twp., MI, introduces the compact LD1000 and LD2000 series **laser drivers**. The LD1000 supports diodes with up to 200mA in current output. Laser output power can be adjusted with an on-board trimpot. The LD2000 offers analog modulation and on-board trimpot adjustment, controlling both laser power and current. The drivers are featured in a new "Laser Diode Reference Manual."

For More Information Write In No. 736

Optical Associates Inc. (OAI), Milpitas, CA, offers the Model 307 **UV Powermeter** to measure up to 2,999mW/cm^2. Developed to measure UV spot curing systems, the 307 has optical elements that reflect IR radiation to allow the wavelength of interest to be measured. OAI says it has tested the 307 on many light sources with outputs above 2000mW/cm^2 at 365nm. The company's related Curemeter is a two-component UV conveyor measurement system that separates the measurement and data reduction/display functions, increasing durability and accuracy.

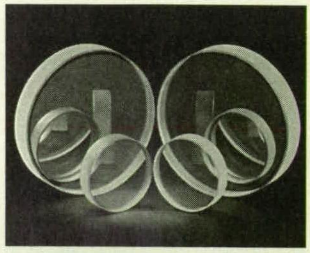
For More Information Write In No. 737

Hamamatsu, Bridgewater, NJ, introduces the S5106 and S5107 surface-mount chip carrier-type silicon **PIN photodiodes** for laser radar detectors, bar-code readers, and other consumer products. The chip carrier packages, only 1.26mm thick, are suitable for surface mounting by reflow soldering. Radiant sensitivity is 0.72A/W at 960nm. Reverse voltage is 30V, power dissipation 50mW, and operating temperature range -20 to +60 degrees C. Dark current is typically 0.3nA for the S5106 and 1nA for the S5107.

For More Information Write In No. 738

New **mirrors for use with Ti:sapphire laser systems** come from Newport/Klinger, Irvine, CA. These Ultrafast mirrors increase reflection bandwidth and reduce pulse distortion through the reflection band, according to the company. Various coatings are offered on flat and concave substrates for cavity and beam-steering applications where reducing pulse distortion is important.

For More Information Write In No. 739

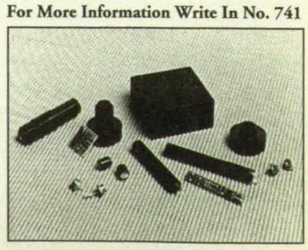


Coherent, Santa Clara, CA, has added two new high-output-power products to its line of Diamond compact **sealed carbon dioxide lasers**. The Diamond 820 provides a minimum of 200W and the Diamond 825 a minimum of 225W. All Diamond models are available as either turnkey systems or modular units for the systems integrator. Their small focused spot size, rapid square-wave pulsing, and high peak power make them suitable for cutting, welding, and drilling a wide variety of metal, ceramic, and organic materials. The company says the line will operate for 10,000 hours without fill or maintenance.

For More Information Write In No. 740

Included among the new line of diode laser assemblies for OEMs from Melles Griot, Boulder, CO, are miniature assemblies, point/spot projectors, line projectors, and power conditioning circuits. Features include rugged packaging, new lens options, and new outline and mounting configurations. Available wavelengths range from 635-1550nm and output powers from 0-200 mW. Also available are a wide range of output beam sizes and fan angles.

For More Information Write In No. 741



NEW PRODUCT SHOWCASE

Resonetics, Nashua, NH, the micromachining systems designer specializing in industrial excimer lasers, now offers its customers a full line of **beam delivery systems and optics** for UV/VUV R&D and in-dustrial applications. The company has also devised an upgrade program so users can improve the performance of existing systems. Pro-ducts offered include optic chambers, ball and socket turning mirror blocks, lens focus adjustment heads, telescopic beam tubes, motorized multiple mask positioners, and a full range of select grade optics. A catalog highlighting beam delivery systems is available.

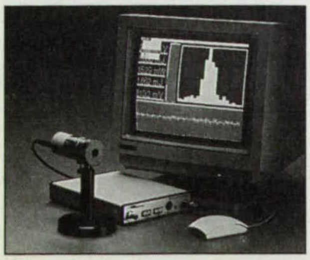
For More Information Write In No. 742

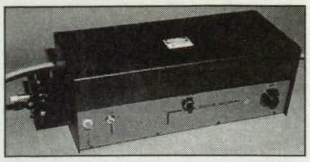
New to the product line of Oriel, Stratford, CT, are UV **nitrogen lasers** with a hard-seal technology that the company says increases tube life up to 100,000,000 shots. It comes in a high-pressure version with a 600ps pulse and a higher-energy version with a 5ns pulse. The company also introduces a dye laser module, tunable from 350-750nm, that attaches to the output of either nitrogen laser. It has two output ports for switching between the nitrogen and the dye outputs. The lasers come separately or as a package.

For More Information Write In No. 744

Molectron Detector, Portland, OR, announces "Windows-like" **joulemeter applications software** for the company's JD501 joulemeter digitizer product. The software emulates Windows operation but maintains the real-time data rates needed for high-repetition-rate pulsed laser applications to 500pps. The software runs on a 386 IBM PC or equivalent with math coprocessor, 200kB of memory, and a mouse.

For More Information Write In No. 745



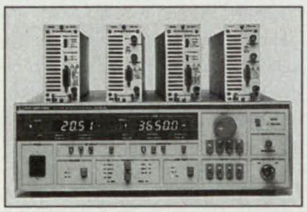


The LP-30 variable-pulsewidth **carbon dioxide laser** is new from Pulse Systems, Los Alamos, NM. Presets allow digital selection of any number of pulsewidths from 5 microseconds to 1 millisecond. Pulsewidth can also be continuously variable over that range. Energy per pulse or peak power can be held constant from 15 microseconds to 1 millisecond. A variable pulsewidth also is available for the company's LP-140 low-pressure transverse-discharge carbon dioxide laser.

For More Information Write In No. 746

ILX Lightwave, Bozeman, MT, has added the LDC-3900 modular **laser diode controller** to its line of laser diode instrumentation. Four rear-panel module bays accommodate an extensive set of user-interchangeable modules, including five current sources with outputs from 100mA-4A, and two thermoelectric temperature controllers that provide 16W and 32W of power. The modules incorporate low-noise performance and protection features. ILX's LDC-3700 controller family has been extended to include a new high-resolution low-current controller (LDC-3712) and a new high-power laser controller (LDC-3752).

For More Information Write In No. 747



CVI Laser, Albuquerque, NM, offers new **stable doubling options** for its C-100 series of arc-lamp-pumped continuous-wave Nd:YAG lasers. Output power at 532nm for the Model C-105 is 250mW, for the C-120 1500mW, and for the C-140 3000mW. The improved doubling option is also available to the C-90 series models. The lasers are useful in applications ranging from laser pumping of both dye and Ti:sapphire lasers, spectroscopy, metrology, interferometry, particle counting, scanning laser microscopy, and many medical and research applications.

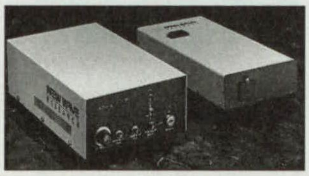
For More Information Write In No. 748

Burleigh Instruments, Fishers, NY, calls its SA-PLUS **optical spectrum analyzer** the highest-finesse confocal Fabry-Perot interferometer available. Finesse is greater than 250. The analyzer has interchangeable mirror sets that enable operation between 250-5000nm for research from ultraviolet to infrared wavelengths. Free spectral range options are 2GHz and 8GHz, and resolution of measurements is greater than 8MHz and 32MHz. The detector sensitivity of 10nW allows spectral analysis of lower-power laser signals.

For More Information Write In No. 749

Now available from New Wave Research, Sunnyvale, CA, are the MiniSys I and II air-cooled **Nd:YAG laser systems** for a wide range of industrial and scientific applications. MiniSys I has a 1pps repetition rate and MiniSys II a 5pps repetition rate. The systems are offered in single- and dual-wavelength configurations; available wavelengths are 1064nm, 532nm, 355mn, and 266nm. Energy levels range from 25mJ at 1064 (MiniSys I Model 106) to 0.25mJ for the dual-wavelength MiniSys II Model 532-266.

For More Information Write In No. 750



A new turnkey **diode laser system** from Opto Power Corp., City of Industry, CA, is completely self-contained and combines reliable diode array technology with the flexibility of fiber optic delivery. The unit delivers up to 18W of continuous-wave optical power, and plugs into a standard 110V outlet. Price is $13,500 in quantities of 1-9.

For More Information Write In No. 751

The new InfraCAM infrared **staring focal-plane array camera** from Inframetrics, Billerica, MA, measures 5.3" X 9.7" X 2.5" and weighs only 3 lbs., including battery, viewfinder, and interchangeable lens. Lenses with focal lengths of 25mm, 50mm, and 100mm are available. The camera can operate continuously for more than 2 hours on a single charge of a commercially available 6V camcorder battery.

For More Information Write In No. 753

Acton Research, Acton, MA, announces a new compact imaging **spectrograph and monochromator**, the SpectraPro-150. Only 7" X 7", the unit features 150mm focal length, an astigmatism-corrected optical system, plus imaging capabilities for multichannel CCD-based spectroscopy. Operating range is from UV-IR with a wide selection of available gratings and accessories. As a spectrograph it offers 5nm/mm dispersion and a 10mm X 25mm focal plane. As a monochromator it features 0.4nm resolution and built-in stepping-motor wavelength drive.

For More Information Write In No. 754

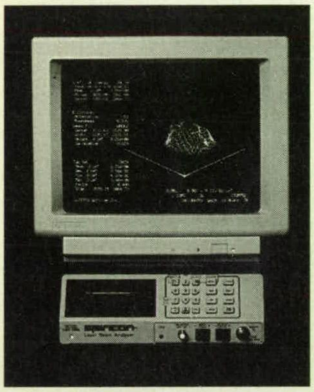
The single-mode Fiber Distributed Data Interface **(FDDI) transceiver** from AT&T Microelectronics, Berkeley Hts., NJ, combines a hermetically sealed 1.3-micron InGaAsP uncooled laser and AT&T's standard 1402U integrated circuit and photodiode. Operating at rates ranging from 10Mb/s-156Mb/s, the transceiver supports transmission at Synchronous Optical Network (SONET), rates OC-1 and OC-3, and Synchronous Transport Mode (STM1), and can be designed into asynchronous transfer mode systems. It employs the industry-standard 2X11 pinout and mates directly to the single-mode FDDI media interface connector.

For More Information Write In No. 755

NEW PRODUCT SHOWCASE

Spiricon, Logan, UT, has a new 4.1 version of its LBA-100A advanced **laser beam analyzer** featuring AUTO-SYNC wireless triggering for pulsed lasers, AUTO-CAL black-level calibration for improved precision and accuracy, and BEAMFINDER for automatically centering the beam profile in the video display. New algorithms, including the ISO knife-edge algorithm, used with AUTO-CAL, provide precise analysis even when beam energy is only 20% of the CCD/vidicon sensitivity.

For More Information Write In No. 756



Janos Technology, Townshend, VT, has a new **coated lens protector line** for carbon dioxide industrial lasers to extend lens life during cutting or welding. NaCl and KCl are both available, with antireflective and moisture-protective coating. Standard sizes are in stock for immediate shipment.

For More Information Write In No. 757

Polytec PI, Auburn, MA, introduces the LIGHTLINE 3-axis **positioning system for fiber optics** and other nanopositioning applications from Physik Instrumente. With a proprietary piezoelectric linear motor, the positioner has a single drive per axis, providing less than 10nm accuracy over a 6mm range. The axes are controlled by a closed loop in steps down to 1nm with any PC-compatible computer. A 3-axis angular positioning module is available as an option.

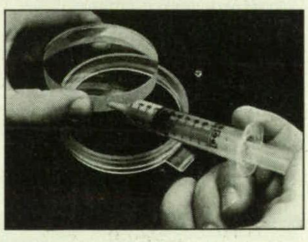
For More Information Write In No. 758

Minolta Corp., Ramsey, NJ, has added the first portable **spectrophotometer** to its CM-500 series. With d/8 geometry that conforms to ISO and DIN standards, the CM-508d is switchable between specular components included and excluded. The sensor, a single-chip silicon photodiode array, allows the unit to measure light simultaneously from 400-700nm at 20nm wavelength intervals. The unit can be connected to any computer through an RS-232C 9-pin D-subminiature connector. Suggested price is $8500.

For More Information Write In No. 760

A new optically clear **epoxy resin system** from Master Bond, Hackensack, NJ, can serve, the company says, at temperatures as high as 204 degrees C. EP30-3 is a low-viscosity two-component composition with a noncritical 3/1 mix ratio with good chemical resistance to acids, alkalis, salts, water, and more.

For More Information Write In No. 761

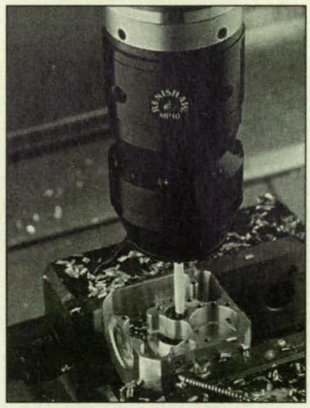


Reynard Enterprises, San Clemente, CA, is making available circular variable **beamsplitters for excimer lasers** and other high-power UV sources. Designed for use at a 45-degree angle of incidence, the dielectric beamsplitters' transmission values can be changed from 10% up to 90% by simple rotation through 270 degrees. Stock filters are available for 248nm and 308nm in 50mm, 100mm and 125mm diameters. Other wavelengths, sizes, and gradient ranges, as well as rectangular filters with linear gradients, also are available.

For More Information Write In No. 762

A new touch-trigger **optical machine tool probe** from Renishaw, Schaumburg, IL, sends and receives optical signals for on/off switching. The company says a shortened activation time permits greater flexibility and reduced cycle time in automatic inspection, part location and on-machine process verification. Repeatability of the probe is ±1 micron. Its receiving unit is hardwired to the machine tool CNC via a Renishaw MI12 interface, which can be adapted to most major controllers from Fanuc, Acramatic, Mazatrol, Yasnac, Heidenhain, Okuma, and others.

For More Information Write In No. 763



Fiberguide Industries, Stirling, NJ, announces a new line of UV-VIS-IR **fiber optic bundles** for remote spectroscopy applications. The bundles come in two configura-tions: spot to slit, for transmissive-mode analysis of samples and light sources; and bifurcated, which enables the user to input light, receive it as reflected from the sample, and direct it to a monochromator. The monochromator, sample, and input ends of the bundle can be customized.

For More Information Write In No. 764

Centronic, Newbury Park, CA, is making available a **photodiode calibration service** utilizing an Acton Research triple grating monochromator that reads only one specific wavelength at a time. The photodiode is scanned and the results recorded through custom spectral scanning software. The company, which also manufactures photodiodes, tests back-calibration, test filter transmission, and related optical parameters. Responsivity can be recorded in A/W with or without bias voltage or in V/W. Accuracy traceable to National Laboratory Standards is ±3% for 400-1200nm and ±8% below 400nm.

For More Information Write In No. 759

New from Wavelength Electronics, Bozeman, MT, is the LDD200-APC series of **laser diode drivers** that the company says bring the high stability and low noise of benchtop controllers to the OEM user. These "IC"-like drivers provide up to 200mA drive current, less than 2μA noise current and better than 0.05% output power stability. Compatible with the industrial environment, the drivers carry a two-year warranty. They feature precision current adjustment and slow-start protection.

For More Information Write In No. 765

Rodenstock Precision Optics, Rockford, IL, is offering a tandem **CCD lens package** that incorporates all the optics necessary to transmit the image from an image intensifier tube directly onto a CCD camera. Two compact designs provide the ability to transmit 15, 20, and 25mm output images directly onto the chip. The combination is available in straight and right-angle configurations.

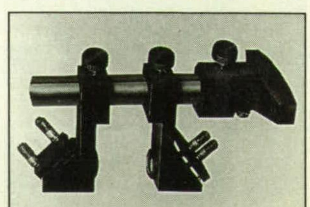
For More Information Write In No. 766

GTFS, Santa Rosa, CA, has released its Beam Analysis VI **beam diagnostics software** for Windows and has issued a new version for the Macintosh. Applications for Beam Analysis VI include characterization of lasers, laser diodes, and other optical sources, tuning, maintenance, and quality control. It is available as a stand-alone application or can be bundled with programming tools including the LabVIEW instrumentation software from National Instruments.

For More Information Write In No. 767

The new **laser beam-steering components** from Data Optics, Ypsilanti, MI, can be used both on optical tabletops and with optical bench or rail mounting. Utilizing V-rod posts, these components are available with micrometer adjustments standard (thumbscrew adjustments are optional), ball-bearing pivots, variable height, and full rotation around the vertical axis. Also available are 45° mirror units.

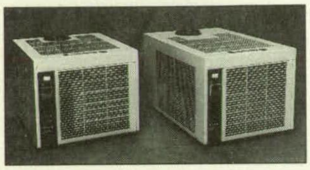
For More Information Write In No. 768



NEW PRODUCT SHOWCASE

The new R-Series **chillers** from Affinity, Union, NH, provide cooling from 1-4kW in a modular design available rack-mountable, stand-alone, or configured to an OEM cabinet. Features include a digital microprocessor, unrestricted component access, and level, flow, and temperature alarms, with RS-232 and interlock capabilities. Affinity's line also includes the F-Series chillers with capacities from 3-50kW, and heat exchangers up to 100kW.

For More Information Write In No. 769



Uniform spherical **silica particles** from EM Industries, Hawthorne, NY, affiliate of E. Merck of Germany, are available under the trade name Monospher. The nonporous spheres, with diameters from 250-1200nm, come in pure silica or with surface modification. Among their uses is light diffusion from sources such as LEDs. The spheres are chemically stable to nitric acid, sulfuric acid, hydrochloric acid, organic acids, ammonia and amines.

For More Information Write In No. 770

The ruggedized multimode **fiber optic couplers** from AMP, Harrisburg, PA, available in configurations ranging from 1X2 to 32X32, offer low optical loss and an operating temperature range of -55 °C to +85 °C. The units are environmentally sealed to withstand the effects of avionic and military use and similar harsh environments. Custom designed packaging is available with options of fiber type, case, connectors, and performance specifications.

For More Information Write In No. 771

The UBC 14 laser-based **noncontact measuring system** from UBM Corp., Roselle, NJ, has a measurement range of 1mm with an accuracy of 0.01 micron. The system can measure surface profile, surface roughness, flatness, and thickness without surface contact. Eight sensor modules for different applications are available, including a Telefocus sensor with 15mm standoff. The total system consists of the laser sensor head, movable XYZ stages, and a computer-based controller.

For More Information Write In No. 772

The SS-550 EPS series of 450W **pulsed Nd:YAG metalworking lasers** from Benchmark Industries, Goffstown, NH, is designed for hard-to-handle and high-reflectivity materials as well as dissimilar metals. The series produces a 50J pulse with less than a 7.4ms pulsewidth for processing hard-to-machine alloys. The electronic pulse switching (EPS) feature enables the operator to select pulsewidths electronically from the computer controller. Two models are available, one for welding, drilling, and cutting and the other a dedicated cutter/driller. Benchmark, a subsidiary of JMAR Industries, also offers a line of laser machining centers with 3-6 axes of motion.

For More Information Write In No. 773

Paracelsus Technology Corp., Severna Park, MD, introduces a torsional vibration **optical sensor** for monitoring torsional strain, rotational speed, and the position of rotating shafts. Providing noncontact measurements of shaft twist to less than half a wavelength, it requires no slip-rings or other moving parts. Range of operation includes shaft speeds from 1-25,000 rpm on shaft diameters of 1.5-28 inches. The sensor has 60dB or more of linear dynamic range and flat frequency response from DC-50kHz.

For More Information Write In No. 774

The Fotonic **fiber optic displacement sensor** from MTI Instruments, Latham, NY, can measure displacement, vibration, or proximity with resolution to 0.01 microinch (2.5 angstroms). The company says the sensors have been used in such applications as modal analysis of computer read/write heads, the vibration amplitude of ultransonic welders, and resonant response of electronic components. Frequency response is from DC-100kHz. A special edge-detector fiber optic probe is available.

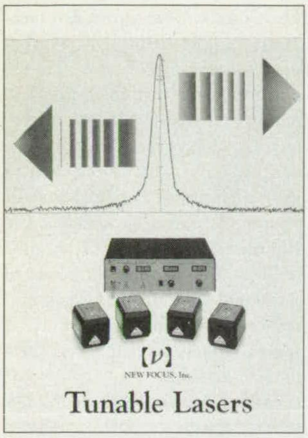
For More Information Write In No. 775

Apex Microtechnology, Tucson, AZ, introduces the PA87, a 450V hybrid **power amplifier** in a 10-pin SIP. The compact MOSFET unit measures 1" long, 0.5" wide and 0.2" high. While delivering 200mA of continuous output current, the op amp has a maximum 3mA of quiescent current. Price in quantities of 100 is $67.50. Apex says key applications include piezoelectric positioning, deformable mirror focusing, and ring laser gyro use.

For More Information Write In No. 776

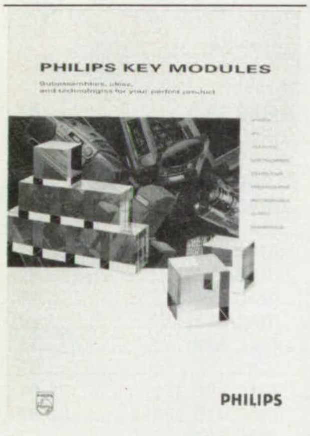
ADVERTISERS INDEX

NEW LITERATURE



New Focus, Sunnyvale, CA, has prepared a 6-page brochure describing its line of **tunable diode lasers** that use piezos instead of stepper motors for continuous tuning over a wide wavelength range. The literature gives specifications of five models with center wavelengths of 670nm, 780nm, 850nm, 1320nm and 1550nm: typical tuning ranges, fine frequency tuning ranges, minimum power, wavelength stability, repeatability, linewidth, side mode suppression, and price. Application details, ranging from wideband communication systems to metrology, spectroscopy, and others that require continuous tuning and narrow linewidth, are given along with warranty information.

For More Information Write In No. 701

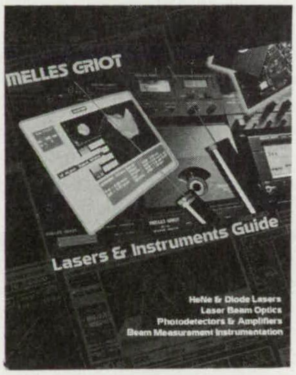


Philips Key Modules, San Jose, CA, has released a 6-page full-color **capabilities folder** describing its CD technology, optics, optical data drives, electro-optical components, magnetic recording modules, hybrids and miniature modules, electro-mechanical modules, and wirewound components for OEMs. The company also has a brochure on its Dutch parent firm's replica aspherical lens capability.

For More Information Write In No. 702

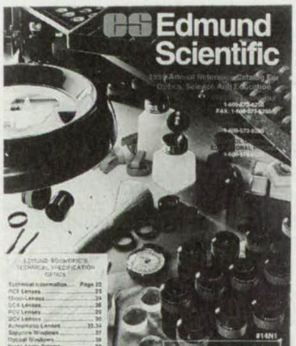
The new **Lasers and Instruments Guide** from Melles Griot, Boulder, CO, is a 356-page reference volume that encompasses HeNe lasers, diode lasers, and an array of laser and photonic instrumentation. Among the latter are lenses, filters, and accessories commonly used with lasers. Product introductions include the WaveAlyzer and BeamAlyzer, computer-controlled instruments that measure laser wavefront quality and intensity profile. Frequency-stabilized lasers have expanded both the HeNe and the diode laser families. Also new are laser power meters (10μW-30W), a 100A pulsed diode laser power supply, a 3A CW diode laser power supply, and spectrum analyzer heads.

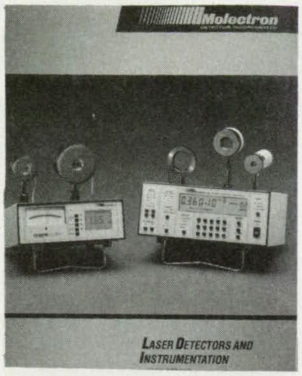
For More Information Write In No. 703



The 1994 **Optics, Science and Education Catalog** from Edmund Scientific, Barrington, NJ, contains more than 8000 science and optical products in its 220 full-color pages. A newly expanded line of off-the-shelf optics and components for OPEM and research applications, including PCX, DCX, PCV and DCV lenses, achromatics, microlenses, sapphire and optical windows, prisms, beamsplitters and corner cube reflectors. Also included are microscopes, telescopes, magnifiers, lab equipment and accessories.

For More Information Write In No. 711



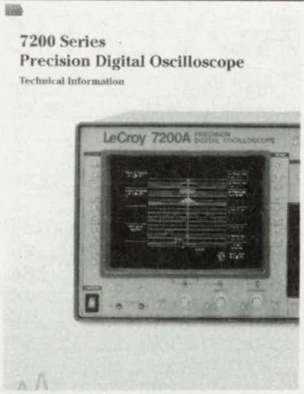


The 4-page full-color brochure from Molectron, Portland, OR, describes **"Laser Detectors and Instrumentation: UV to Far Infrared."** Among featured products are joulemeter probes and instruments, PowerMax laser power meters, radiometers and detector amplifiers, pyroelectric hy-brid detectors, thin-film IR polarizers and free-standing wire grid polarizers.

For More Information Write In No. 704

The 1994 **Fiber Optic Product Catalog** from The Light Brigade, Kent, WA, is available. Product lines included are connectors, attenuators, patch panels, cable, supplies, tools, test equipment, and splicing equipment. Light Brigade's offerings of fiber optic training videos, courses, and manuals are also described.

For More Information Write In No. 705



Technical information on the 7200 Series precision **digital oscilloscope** is the subject of a 10-page full-color pamphlet from LeCroy, Chestnut Ridge, NY. It gives specifications for the three models in the series, as well as information on the company's patented SMART TRIGGER that captures elusive events, and on the series' waveform analysis, unattended monitor and automated test capabilities.

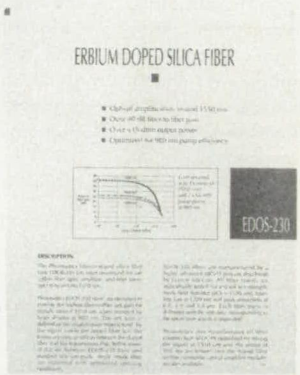
For More Information Write In No. 706

A 6-page full-color publication from Galileo Electro-Optics, Sturbridge, MA, highlights a new **fiber optic remote IR spectroscopy system** for real-time process monitoring. It describes the features and benefits of the IR Link method development and IR Link multichannel remote IR spectroscopy systems, and provides details of the fiber optic spectral ranges, diagrams, cable descriptions, and sensor options available, as well as industries and typical applications.

For More Information Write In No. 707

Ohara, Somerville, NJ, has produced a 4-page pamphlet on the new CLEARCERAM 55 and 63 **ultra-low-expansion glass**. The company cites its ultra-low thermal expansion, excellent optical homogeneity and transparency, excellent finished surfaces and high mechanical strength. CLEARCERAM 55 is characterized by lower thermal expansion, and CLEARCERAM 63 by higher transmittance.

For More Information Write In No. 708



A series of single-page 2-color specification sheets on **fiber optic telecommunications instruments** is available from Photonetics, Wakefield, MA. These describe and numerically characterize the company's lines of advanced fiber optic couplers, erbium-doped silica fiber, erbium-doped fiber amplifier modules, and wavelength-tunable laser diode sources.

For More Information Write In No. 710

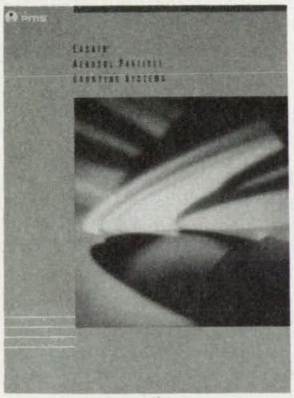
Lumex Opto/Components, Palatine, IL, has issued a full-color 60-page catalog with specifications and dimensions on more than 2500 **LEDs and LED assemblies**, including more than 100 new items such as surface-mount units, arrays, light bars and transluminators.

For More Information Write In No. 709

NEW LITERATURE

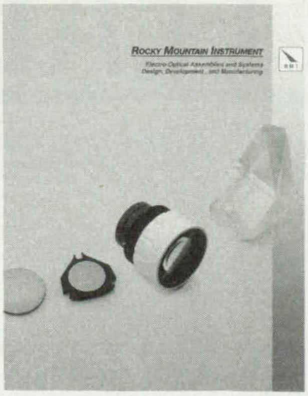
Product literature from Particle Measuring Systems, Boulder, CO, features a complete family of **laser-based air-particle counting systems**. The microprocessor-controlled in-struments size and count particulates at minimum sensitivities of 0.1-0.5 microns, for use in environmental monitoring and clean-room certification. The 4-page full-color brochure gives specifications for eight models.

For More Information Write In No. 712



EG&G Ortec, Oak Ridge, TN, has published a 16-page full-color brochure about its new MCS-plus **multichannel scaler PC plug-in card** that the company says offers new versatility for multichannel scaling, multiple-stop time spectrometry, and signal averaging. Designed for lidar, mass spectrometry, and laser-induced chemical reactions, among other applications, the MCS-plus has dwell times from 2 microseconds to 1800 seconds, 8192 memory channels, and computer-controlled single-channel-analyzer (SCA) thresholds. An SCA sweep mode simplifies setup for pulse height selection. Ortec says the MCS-plus can also be used for neutron time-of-flight spectroscopy, time-resolved single-photon counting, and Mossbauer experiments.

For More Information Write In No. 713

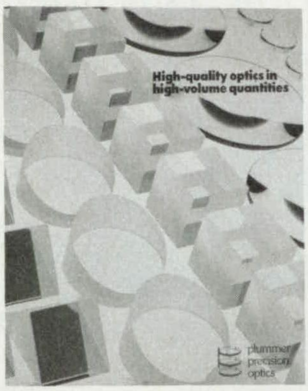


Rocky Mountain Instrument, Longmont, CO, has published a **1994 capabilities brochure** detailing its in-house engineering, R&D, fabrication, coating and environmental testing facilities. Along with a brief company history the publication contains summaries of the optics, materials, and assemblies available and some of their applications.

For More Information Write In No. 714

The 8-page full-color capabilities brochure from Plummer Precision Optics, Pennsburg, PA, outlines the company's scope in **"High-quality optics in high-volume quantities."** The booklet describes the design engineering department, the polishing and coating facilities, and quality control procedures that incorporate statistical process control. The company can manufacture custom optics from 0.2-12" in diameter.

For More Information Write In No. 715

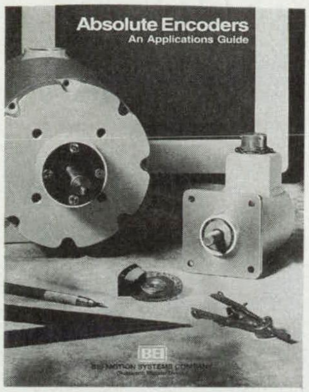


A 4-page booklet from Photon Technology International, South Brunswick, NJ, describes the **monochromators** in the company's Optical Building Blocks line. There are specifications and application information on the new Models 101 and 102 quarter-meter-class Czerny-Turner monochromators, and a guide to grating selection.

For More Information Write In No. 716

BEI Sensors and Motion Systems, Chatsworth, CA, is offering an applications guide on **absolute optical encoders**. Its 16 pages give information on achieving optimum design performance in motion control and positioning systems. Also covered are voltage selection and power issues.

For More Information Write In No. 717



New from Newport, Irvine, CA, is a color booklet detailing the company's **light measurement instrument family** for 1993-94. Included in its 16 pages are multifunction optical meters, picowatt optical power meters, handheld optical power meters, low-power and high-power detectors, energy detectors, integrating spheres, and biased photodetectors.

For More Information Write In No. 718

The SUMMIT ultra-accuracy **coordinate measuring system** from Giddings & Lewis Measurement Systems, Dayton, OH, is detailed in a 6-page full-color booklet. The unit's high throughput and accuracy (better than 2mm), laser scales, fiber optic delivery system, high inspection speed (five times faster than others in its accuracy range, the company says), design and construction features are described and illustrated.

For More Information Write In No. 719

Perkin-Elmer, Norwalk, CT, offers a new 12-page full-color brochure about the Lambda 2S **UV/VIS spectrometer**. Underscoring its flexibility, the pamphlet describes its double-beam optics, 190-1100nm wavelength range, and scan speed from 7.5-2880nm/min. Applications suited to the Lambda 2S include water analysis, autosampling, remote sampling with fiber optics, and kinetic analysis for enzyme and substrate determinations. Highlighted in the brochure are the unit's basic methods for parameter selection, including substrate analysis, time-drive, and wavelength programming.

For More Information Write In No. 720

The 34-page full-color catalog II from Summers Laboratories, Ft. Washington, PA, describes the company's **Lens Bond optical cements**, adhesive systems, decementing agents, cementing supplies, and accessories. The cements meet or exceed military environmental specifications, and can be shipped off the shelf. The catalog has technical information on physical and adhesion properties, solvent and thermal resistance, environmental testing, and laser applications.

For More Information Write In No. 721

The **1994 catalog** of Titan Tool Supply, Buffalo, NY, has been issued. The largest ever published by the company, it has 120 pages outlining what Titan calls the industry's most complete line of optical metrology and viewing instruments, general inspection tools, microfinishing equipment, and video viewing systems. Among new product offerings are the IMF series microscope-videoscope for video measurement/alignment, the FX-6 stereo microscope of a variety of industrial applications, and the GOILB-300W fiber optic illuminator for borescopes and optical comparators.

For More Information Write In No. 722

INDUSTRY LEADERS

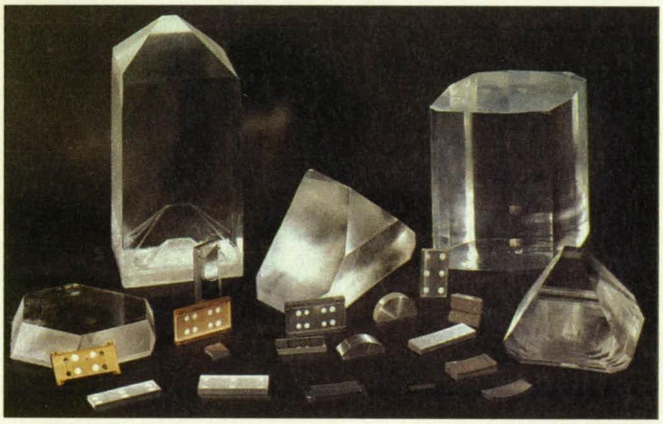
Profiles of Pathsetting Companies In The Photonics Field

CRISMATEC

WORLD CLASS CRYSTALS

Through its subsidiaries Crismatec and Bicron, Saint-Gobain is the world's largest producer of monocrystals for the optical and nuclear radiation detection markets.

There are three Crismatec manufacturing sites in France. The group specializes in nonlinear optical materials, x-ray monochromator crystals, and scintillation crystals.



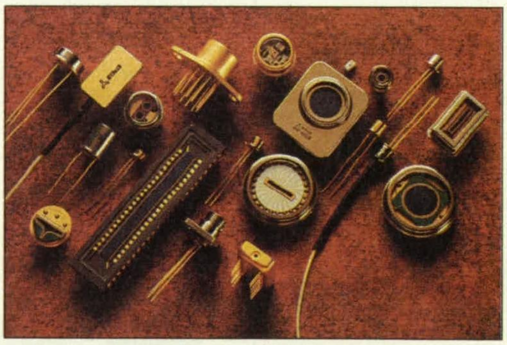
- Crystals for x-ray spectrometry: LiF, quartz, silicon, germanium, PET, EDT, ADP, beryl, TAP, RAP, KAP, CsAP, and lead stearate.
- Crystals for nonlinear optics: KDP, DKDP, POM, NPP, LNO, and LTO.
- Scintillation crystals for nuclear radiation detection: NaI (T1), CsI (T1), CsI, and BGO.
- Garnet substrates and epitaxial films: GGG, SGGG, YAG, YAG:Ce, and magneto-optical films.
- Laser crystals: Nd:YAG, Ho,Tm,Cr:YAG, Er:YAG, and Nd:YLF.
- Epi-ready wafers of InP.

Contact: Christine Keller, Bicron, 6801 Cochran Road, Solon, OH 44139. Tel: 216-248-7400; Fax: 216-349-6979.

EG&G CANADA LTD.

SEMICONDUCTOR LASERS, EMITTERS AND PHOTODETECTORS

Based in Quebec, EG&G Canada Ltd. (formerly GE/ RCA Electro-Optics Division) is part of the EG&G Optoelectronics Group. Parent company EG&G Inc., headquartered in Wellesley, Massachusetts, is a diversified Fortune 200 company with over 30,000 employees.



EG&G Canada features one of the most advanced facilities of its kind in North America: a 100,000-square-foot product development and manufacturing plant incorporating Class 100 and Class 10,000 clean rooms, an electronics development and test laboratory, and a prototype machine shop, all supported by a team of scientists, engineers, and technicians with experience in semiconductor emitter and detector technologies.

EG&G Canada routinely meets industry's and the military's most rigorous quality and performance standards for applications such as laser rangefinding, optical proximity fusing, tracking, target designation, weapons fire simulation, line-of-sight optical communications, and OEM instrumentation and test equipment.

Regarded as one of the industry's premier silicon avalanche photodiode suppliers, EG&G Canada specializes in manufacturing a wide range of high-performance semiconductor lasers, emitters from UV to near-infrared, and photodetectors using silicon and III-V compound technologies. Over 70% of the products and services are customized for defense, aerospace, fiber optic communications, medical instrumentation, and industrial applications. These include pulsed short- and long-wavelength lasers, high-performance LEDs, CW lasers, silicon PIN detectors, InGaAs PIN detectors, and silicon and InGaAs avalanche photodiodes.

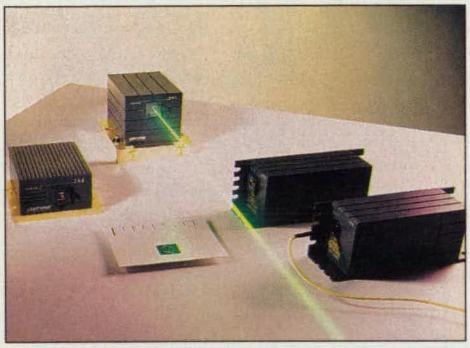
Contact: Heather Nochon, EG&G Canada Ltd., 22001 Dumberry Road, Vaudreuil, Quebec, Canada J7V 8P7. Tel: 514-424-3388; Fax: 514-424-3411.

LIGHTWAVE ELECTRONICS

DIODE-PUMPED LASERS

Since 1985, Lightwave Electronics has been a leading innovator of compact, efficient, and reliable solid-state laser systems based on laser-diode pumping. They are replacing lamp-pumped solid-state and gas discharge lasers, as well as opening new applications.

Lightwave offers many unique products—from continuous-wave (CW) single-frequency to Q-switched to mode-locked lasers—that are used in a wide range of applications including basic research and development, communications, fiber optic sensing, and semiconductor processing. Higher powers, greater pulse energies, and new wavelengths will become available, leading to additional applications.



Contact Phil Clark, Lightwave Electronics, 1161 San Antonio Road, Mountain View, CA 94043. Tel: 415-962-0755; Fax: 415-962-1661.

CW single-frequency lasers (see photograph) incorporate a monolithic cavity design known as the nonplanar ring oscillator which yields superior linewidth and frequency stability compared to other laser structures. Models also have active noise reduction, fiber-coupled output, and an OEM-compatible configuration.

Q-switched lasers made by Lightwave are available with pulse durations from 3 to 50ns, repetition rates to 50kHz, and a wide range of pulse energies. These models have an excellent reliability record in demanding OEM applications. They also feature pulse equalization and burst modes of operation.

Mode-locked lasers available from Lightwave operate at fixed repetition rates from 75 to 250MHz with pulse durations from 10 to 300ps and average power levels to 200mW. Active mode-locking, diode pumping, and timing stabilization combine to provide significantly less timing jitter compared to conventional mode-locked lasers.

Optical heterodyne systems offered by Lightwave optically deliver signals from 10MHz to 60GHz through an optical fber or in free space. These signals result from the phase-locked difference frequency between two Lightwave single-frequency lasers produced by the Laser Offset Locking Accessory (LOLA).

LiCONiX

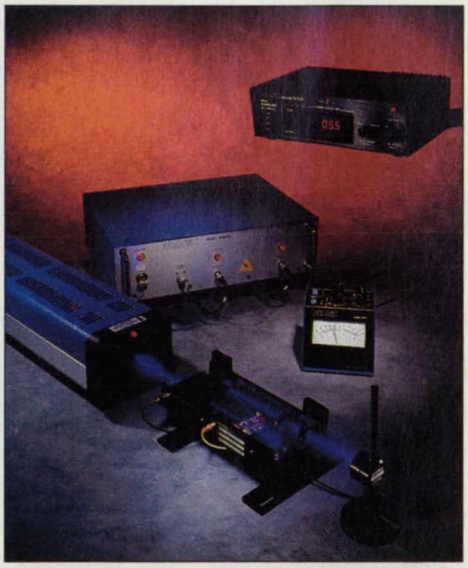
HeCd, ION LASERS, AND ACCESSORIES

Founded in 1972, LiCONiX, of Santa Clara, CA, is the oldest manufacturer of compact blue lasers. Combining over 20 years of manufacturing experience with one of the finest engineering staffs in the industry, LiCONiX continues to be a world-leading manufacturer of HeCd lasers, ion lasers, and laser accessories.

Innovative products that satisfy customer needs will enable LiCONiX to retain market leadership well into the next century. The Embosser II, the world's most powerful HeCd laser, was released last month, meeting industry demands for a higher-powered 442nm laser. The Embosser II delivers up to 200mW (150mW TEM_{00}) of power at 442nm, and is available in coherence lengths of 10cm, 30cm and an unprecedented 50cm. The high-powered laser is also available at 325nm and our patented (US Pat #5257278) 354nm.

Last year, LiCONiX introduced the world's first 354nm HeCd laser. The compact UV laser marked a revolution for biological fluorescence applications including confocal laser microscopy, lifetime fluorescence spectroscopy and flow cytometry. Easy to use and inexpensive to operate, the LiCONiX 354nm laser is an attractive alternative to expensive argon ion lasers. Air-cooled and using standard 117VAC, the 354nm laser costs less to buy, uses less electricity, eliminates the need for water (and wat-er bills), and has lower re-tubing costs.

LiCONiX was the first company in the world to successfully mate the portability of air-cooled ion lasers with the power of water-cooled models. This innovation has allowed ion lasers to be used in revolutionary applications ranging from the Space Shuttle tank inspections to the placement of lasers on blimps.

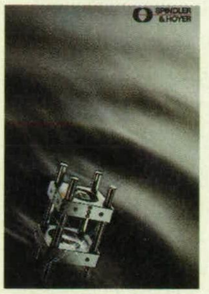


Contact: Michael M. Fisk, LiCONiX, 3281 Scott Blvd., Santa Clara, CA 95054; Tel: 1-800-825-2554; Fax: 408-492-1303.

Other products include a state-of-the-art laser stabilizer, a user-friendly high-performance power meter, a turnkey laser diode system, a laser diode driver and a thermoelectric cooler/temperature controller.

LITERATURE SPOTLIGHT

Free catalogs and literature for Laser Tech Briefs' readers. To order, write in the corresponding number on the Reader Information Request Form (page 51).



NEW PRECISION OPTICS/ MECHANICS CATALOG

A new 400 page catalog of precision optics and mechanics is now available from Spindler & Hoyer, Inc. Over 3,500 products are described including achromats, mirrors, fiber optics, coatings, microbench/ macrobench, lightsources, positioning equipment, optoelectronics and optical tables and table mounting hardware.

Spindler & Hoyer Inc.

For More Information Write In No. 300

AUTOMATIC OPTICAL TESTING

OPTOMATIC is the first fully-automated test instrument featuring fast, ultra-accurate, objective performance characterization of optical components and lens systems. Focal length, flange focal length, radius of curvature, angles and power of wedges and prisms, MTF and centering errors can be precisely measured. Typical accuracy is 0.05% for focal length, 0.002 diopter for power of prisms and less than 1 arc sec. for angles.

Mildex Inc.

For More Information Write In No. 301

HIGH GAIN DETECTOR FOR LIGHT MEASUREMENT

A new SHD-1 data sheet describing the SHD033 High Gain Silicon Detector for low level light measurement in any optical unit is available from IL. The device provides the gain of a photomultiplier with the stability of a silicon photodiode. The SHD033 is used with the IL1700 Research Radiometer/Photometer.

International Light, Inc.

For More Information Write In No. 302

COMPUTER-BASED INSTRUMENTATION

Free 1994 catalog of hardware and software for computer-based instrumentation. Features software for Windows, Windows NT, Macintosh, UNIX, and DOS, including LabVIEW, LabWindows, and the new LabWindows/CVI. Describes IEEE 488.2 interfaces, plug-in data acquisition boards, VXIbus controllers, and signal conditioning accessories. Customer education classes also detailed. Includes tutorials and glossary.

National Instruments

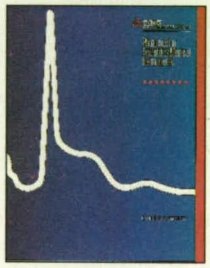
For More Information Write In No. 303

PXL™ HIGH RESOLUTION DIGITAL CAMERA

This brochure describes the PXL™ high speed, modular camera system. PXL delivers low noise and high frame rates for demanding quantitative imaging. With variable readout rates to 4 MHz, this cooled 12-bit camera system is well suited to dynamic and/or low-light applications. For more information, contact Photometrics at 602-889-9933.

Photometrics

For More Information Write In No. 304



PHOTONICS FOR SCIENTIFIC/MEDICAL INSTRUMENTS

EG&G Optoelectronics has published a new short form catalog and selection guide containing its most popular photonic products for use in analytical instruments and medical applications. This 28 page book is organized by product section, including camera tubes, image sensors, laser diodes, UV-VIS-IR photodiodes, IR emitters and phototransistors, and a wide range of high quality lamps and flashtubes. 345 Potrero Avenue, Sunnyvale, CA 94086.

EG&G Optoelectronics

For More Information Write In No. 305

DIODE-PUMPED LASERS

- CW
- Q-switched
- Mode-Locked

Precise. Reliable. Compact. Whether in communications, material processing or basic research, high performance diode-pumped lasers continue to lead the way. And Lightwave has been there from the beginning offering time-proven lasers and fully engineered systems. We may have one for you. Tel: 415-962-0755. Fax: 415-962-1661.

Lightwave Electronics

For More Information Write In No. 306

TOTAL GAS MANAGEMENT

An integrated package of products and services designed to produce optimal lasing results for you. Ultraray® gases for excimer, CO_2, and chemical lasers, local stocking, gas handling and purification equipment, gas cabinets, laser applications lab, emergency response teams, and 800 line for technical support.

Air Products and Chemicals, Inc.

For More Information Write In No. 307

SPECIALTY GAS AND EQUIPMENT CATALOG

Free! The 1993 rare and specialty gas and equipment catalog from Spectra Gases of Irvington, NJ, contains specifications on rare gases, excimer laser gas mixtures, halogen gas premixtures, helium-3 and isotopic gases, research gases and mixtures, gas safety cabinets, and automatic and manual gas-handling systems. Krypton and argon ion-laser tube remanufacturing, halogen scrubbers, and "oil-free" vacuum pumps are highlighted.

Spectra Gases

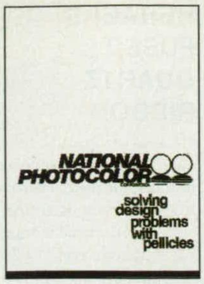
For More Information Write In No. 308

FREE LIGHT RESEARCH CATALOG

Oriel's new Volume II Product Guide: **Light Sources, Monochromators & Detection Systems** is a 528 page technical reference manual and product catalog in one. New, technically advanced products to make, move and measure light include UV to NIR pulsed light sources, nitrogen and tunable dye lasers, calibrated irradiance sources and single and dual beam scanning spectrophotometers. Tel: 203-377-8282. Fax: 203-375-0851.

Oriel Corporation

For More Information Write In No. 334

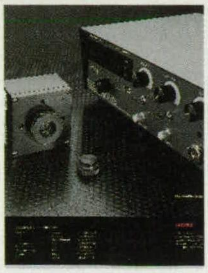


PELLICLE BEAM-SPLITTERS

Literature covering full specifications of Pellicles available. Standard—1" x 6" ID; 5" x 7" Rectangular, Truncated Cylinders, Custom Membranes—Special thicknesses, UV, Visible, IR applications. Critical reflection flatness/transmitted wavefront specifications met and documented. National Photocolor Corp., 428 Waverly Ave., PO Box 320, Mamaroneck, NY 10543-0320. Tel: 914-698-8111. Fax: 914-698-3629

National Photocolor Corporation

For More Information Write In No. 335



LASER DIODE TURN-KEY SYSTEMS

The Diolite 800 is a fully engineered laser diode turn-key system featuring built-in optical power, temperature and drive current control. These parameters can be easily monitored through a front panel digital display. Other standard features include: modulation circuitry (TTL and analog) with rise times less than 10 ns, PD monitor feedback circuitry for optical power stabilization, bias control, spike and transient protection circuitry, and beam collimation control.

LiCONiX

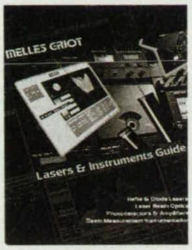
For More Information Write In No. 336

POLARIZATION OPTICS

Meadowlark Optics offers a free 34-page polarization optics catalog/handbook featuring our new *Shape-Shifter*™ linear array spatial light modulator. Other products include achromatic & zero-order polymer retarders, beamsplitting polarizers, Pockels cells, optical isolators, and precision LC retarders, shutters, circular polarizers & tunable filters. Tel: 303-776-4068; Fax: 303-776-5856.

Meadowlark Optics, Inc.

For More Information Write In No. 337



Melles Griot introduces its comprehensive new 356-page **Lasers and Instruments Guide**. Presenting Helium Neon lasers, diode lasers, and an array of laser and photonic instrumentation in one easy-to-use reference volume, it includes a variety of optical lenses, filters, and accessories commonly used with laser products. Tutorial background is provided in the areas of Gaussian beam laser theory, laser wavefront and frequency characteristics, and quantum detector theory.

Melles Griot

For More Information Write In No. 338

PC IMAGING BOARD

Literature is available for the 4MEG VIDEO Model 12 image capture, processing and display board for the PC. The Model 12 features sampling/display rates up to 50 MHz, 64 Mb of image memory and 50 MHz processor. The Model 12 interfaces to most sources for single or sequential image capture. The literature describes features of the Model 12, along with information regarding software and interface options.

EPIX Inc.

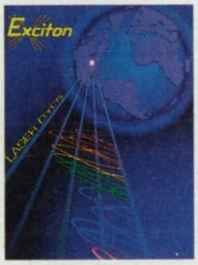
For More Information Write In No. 339

ACHIEVING OPTIMUM LASER PERFORMANCE

Koolant Koolers, Inc. is offering a brochure on its standard and custom-designed single- and dual-circuit water chillers for lasers. The dual-circuit models permit optimum cooling of resonator and optics for increased power and decreased beam diameter. All models can maintain required coolant temperature, with fluctuations as small as ±1 °F (±.56 °C), if required.

Koolant Koolers

For More Information Write In No. 340

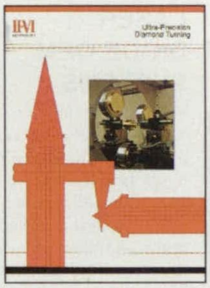


LASER DYES

With Exciton, you get a specialized team of professionals knowledgeable in the field of laser dyes. Since more than one dye may cover a given spectral region, we provide the latest information concerning the best dye selection for a specific laser system and application. Exciton Inc., PO Box 31126, Overlook Station, Dayton, OH 45431.

Exciton Inc.

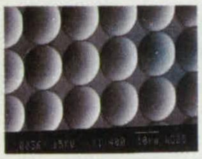
For More Information Write In No. 341



Exceptional ultra-precision diamond turning is now available from II-VI Inc., Saxonburg, PA. II-VI, a worldwide leader in infrared technology, utilizes a Nanoform 600 to achieve feedback resolution of 1.25 nanometer with CNC, interferometer controls. Workpiece capacity is 600 mm in diameter. Two axis diamond turning, combined with advanced optical technology, provides optimum results for aspheric focusing lenses, metal mirrors, transmissive optics and related assemblies. For complete information, call 412-352-5223.

II-VI Incorporated

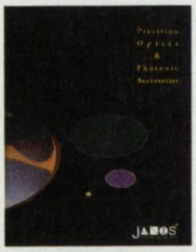
For More Information Write In No. 342



Teledyne Brown Engineering, Electro-Optics Products Group has added refractive microlens arrays to their optics product line. Refractive microlens arrays offer superior performance across the visible/near-IR spectrum, when application requires a fast system with a broad bandwidth. The components are currently available in fused silica, silicon, and germanium with other substrates under development. Microlens parameters: tens of micrometers in diameter, F/#s from 2 to 20, spherical or cylindrical shapes, and variable spacings.

Teledyne Brown Engineering

For More Information Write In No. 343

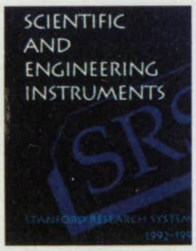


NEW JANOS CATALOG!

Janos Technology Inc. has a new catalog of optical components, accessories, and services available from stock. In addition to the traditional selection of IR-VIS-UV optics there are many new standard items including broadband IR beamsplitters, CaF_2 and ZnSe prisms, BBAR windows, ZnSe aspheres, CPC's, and much more.

Janos Technology

For More Information Write In No. 344

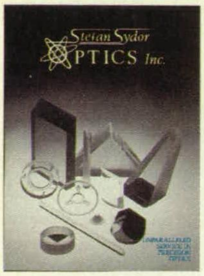


PRECISION TEST AND MEASUREMENT EQUIPMENT

Stanford Research Systems' 1992-93 Catalog contains complete specifications, technical discussions and application notes on their line of scientific and engineering instruments. This 160 page catalog includes the latest function generators, spectrum analysers, lock-in amplifiers and delay generators, and is a useful reference for a wide range of test and measurement applications. Tel: 408-744-9040.

Stanford Research Systems

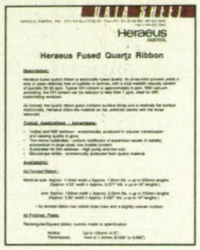
For More Information Write In No. 345



Fabricates optical components including flats, filters, lenses, magnifiers, mirrors, prisms, and windows; optical materials including filter glass, quartz, silica, silicate glass, and IR & UV materials. Repairs and refurbishes laser rods. Grinding & polishing service for all types of crystals. Capabilities include double sided grinding and polishing on machines up to 48 in. diameter.

Sydor Optics, Inc.

For More Information Write In No. 346

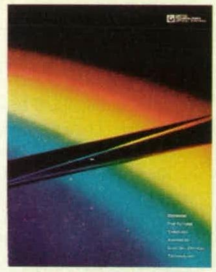


HERAEUS FUSED QUARTZ RIBBON

Heraeus electrically fused quartz ribbon is produced in a strip or plate relatively free of bubbles or airlines, with a total metallic impurity content of typically 20-50 ppm. Typical OH content is approximately 8 ppm. With vacuum annealing, the OH content can be reduced to less than 1 ppm, ideal for NIR transmitting windows.

Heraeus Amersil Inc.

For More Information Write In No. 347



E-O Technology

UTOS designs and manufactures lasers, precision optical components, and adaptive optical components/systems for aerospace/defense, scientific and industrial markets. This colorful brochure describes our range of products which includes ultra-compact, durable CO_2 lasers; transmissive and reflective optical systems; lightweight, stiff, thermally stable silicon carbide components; deformable and fast steering mirrors; wavefront control and compensated imaging systems; and a full line of custom coating services.

United Technologies Optical Systems, Inc.

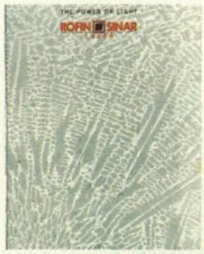
For More Information Write In No. 348

HIGH VOLTAGE POWER SUPPLIES

This catalog from Bertan contains 100 pages of information on solutions to high voltage power supply requirements. Detailed product information on instruments, modules, and NIM power supplies is provided. Standard and custom designs are available for OEM or laboratory applications.

Bertan High Voltage

For More Information Write In No. 349



LASER TECHNOLOGY AND APPLICATIONS

An 18-page brochure available from Rofin Sinar, Inc. provides a concise examination of laser technology and its expanding applications in the manufacturing environment. Detailed are the elements and concepts of lasers critical to modern industry: versatility and flexibility; precision, control, and speed; and the laser's present and potential applications in welding, cutting, drilling, surface treatment, and product identification. Individual sections discuss CO_2 and Nd:YAG lasers, laser marking systems, and Rofin Sinar's capabilities and resources.

Rofin Sinar, Inc.

For More Information Write In No. 350

LASER DIODE OPTICS

A full line of precision optics offered by Optima Precision, Inc., West Linn, Oregon, is for use with laser diode systems including glass & plastic objective and collimating lenses, collimated diode lasers, spherical & cylindrical lenses, beamsplitters, dielectric mirrors, windows, filters, anamorphic, and cube prisms. Applications include alignment, measurement, inspection systems, particle sensors, and bar code readers. Contact Dick Schmitz. Tel: 503-638-2525; Fax: 503-638-4545.

Optima Precision Inc.

For More Information Write In No. 351

LASER DIODE OEM SYSTEMS

Power Technology's new catalog features their complete line of high-quality diode laser systems and components. All systems are fully integrated to include optics and diode-driving electronics. The full product line includes wavelengths from 635 nm to 1550 nm, anamorphic and astigmatic correcting optics, precise beam pointing, thermoelectric control, a CDRH certified model, and many mechanical and electrical accessories. Tel: 501-568-1995; Fax: 501-568-1994.

Power Technology, Inc.

For More Information Write In No. 352

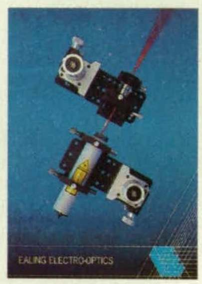
LEADERS IN INFRARED DETECTORS

EG&G Judson's new 1994 catalog features 53 pages of new and improved products that meet the evolving challenges of the marketplace. Emphasis has been placed on custom engineering services that include:

• Design of specialized detectors • Cooler systems • Preamplifier electronics • Multi channel detector arrays • Space and MIL spec qualified detectors. Tel: 215-368-6901; Fax: 215-368-6927.

EG&G Judson

For More Information Write In No. 353



EALING PRODUCT GUIDE

Ealing's Product Guide devotes over 400 pages, covering in excess of 3,500 items, to optical and electro-optical products. Included are lenses, mirrors, filters, high precision positioners, optical mounts, microscope components, HeNe lasers, laser diodes, optical tables, optical benches, and light sources. Ealing Electro-Optics 800-343-4912.

Ealing Electro-Optics, Inc.

For More Information Write In No. 354

PYROELECTRIC LASER/ ENERGY METERS

Models PE10/PE25/PE50.

• No dependence on pulse duration or rate
• High repetition rates up to 5 KHz
• Wavelength correction
• OEM heads with built-in electronics available
• High damage threshold

Displays: Average energy, histogram, frequency, exposure, power and energy graphs. Phone: 1-800-383-0814; Telefax: 508-664-0309.

Ophir Optronics, Inc.

For More Information Write In No. 355

CAMERA-BASED BEAM PROFILING

PHOTON's BeamGrabber offers the fastest, most accurate means of tuning a laser cavity. The design of this cost-effective product focuses on sampling speed and measurement accuracy related to real-time qualification of a beam's energy distribution. The result is instantaneous, precise values that enable quick, consistent adjustments of optical systems.

Photon Inc.

For More Information Write In No. 356

40,000+ REASONS WHY YOUR AD BELONGS HERE

LASER TECH BRIEFS' LITERATURE SPOTLIGHT SECTION OFFERS A LOW-COST WAY TO REACH OVER 40,000 INDUSTRY AND GOVERNMENT LEADERS WITH YOUR ADVERTISING MESSAGE. THESE ARE TECHNOLOGY MANAGERS, DESIGN ENGINEERS, AND SCIENTISTS WITH TREMENDOUS BUYING POWER. THE SPRING 1994 ISSUE IS YOUR NEXT OPPORTUNITY TO USE THIS HIGH-IMPACT SALES TOOL. FOR MORE INFORMATION OR TO RESERVE SPACE IN LITERATURE SPOTLIGHT, CONTACT YOUR LASER TECH BRIEFS SALES REPRESENTATIVE (LISTED ON PAGE 12) OR CALL ROBERT CLARK AT (212) 490-3999.